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NHL Steam Schooner Wapama
Condition Survey and Preservation Recommendations

Richmond, CA

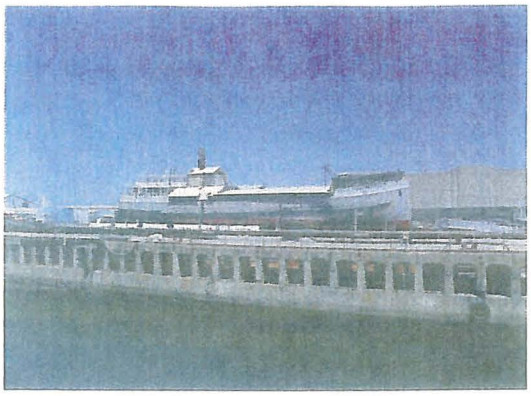
November 2005

Phase 1A Final Report

ARCHITECTURAL RESOURCES GROUP
Architects, Planners & Conservators, Inc.

S.S. WAPAMA NHL STEAM SCHOONER SURVEY & EVALUATION
Richmond Reserve Shipyard
Richmond, California

Hazardous Materials Survey Report



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July 5, 2005

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NHL STEAM SCHOONER *WAPAMA*
CONDITION SURVEY

Phase 1A Final Report

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Exhibits

Wapama Condition Survey prepared by BMT Designers & Planners Inc.

Hazardous Materials Survey Report prepared by Winzler & Kelly Consulting Engineers

Phase 1A Final Report

Background

Architectural Resources Group (ARG) has been retained by the National Park Service (NPS) to provide a two-phase Condition Survey of the National Historic Landmark Steam Schooner *Wapama.* This vessel, built in 1915, is the last survivor of over 200 built and is currently resting on a barge at the Richmond Reserve Shipyard in Richmond, CA. *Wapama* was transferred from the water to the barge about 25 years ago because of her deteriorated condition and fears that she might sink at the San Francisco Maritime Historic Park pier. Since then she has received sporadic maintenance, and the ravages of time and exposure to weather and fresh water have taken a heavy toll.

To assist in the evaluation, ARG, as Team Leader, has retained the services of BMT Designers & Planners (D&P) of Arlington, VA for naval architecture evaluation with assistance from Allen C. Rawl Inc. (ACR), experts in wooden ship preservation and construction, and Winzler & Kelly, Consulting Engineers (W&K) of San Leandro, CA for evaluation of the presence of and nature of hazardous materials. Several meetings and on-board surveys have been conducted beginning in mid June 2005 with the goal of providing updated information as to the safety and stability of the vessel and the barge, updated structural analysis of the vessel, and recommendations for near and longer term actions to stabilize and possibly dismantle parts of the vessel. This report reviews the first phase of the work and generally covers the condition of the vessel and identifies a range of action options for consideration by the NPS. The results of this Report will provide the basis for the second phase of the work which will be to identify and evaluate preservation options and select one of the suggested options, or variation thereof, to study in further detail. In addition, at NPS request, we have contracted with the University of Minnesota through the USDA Forest Products Laboratory to perform a physical condition assessment of the main structural members to aid BMT D&P in their analysis in Phase 1B. Based on that report, the information herein may be supplemented and/or revised.

Executive Summary

The significance of the *Wapama* is that she is the last survivor of her breed and she represents an important link in the transition from the wooden sailing schooners of the 19th Century to the steel cargo ships that would be developed shortly after in the late teens and twenties. She and others like her plied the waters of the Pacific Coast for many

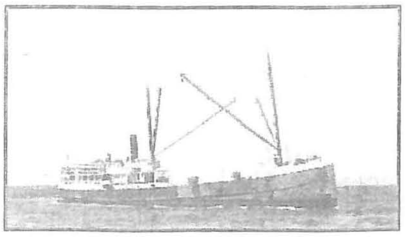
years furnishing the lumber from Northern California and the Northwest to develop the cities and towns to the south.
Wapama was in a deteriorated condition when she was removed from the water. After 25 years out of the water she is in much worse condition, such that there is little if any of her original hull materials that can be saved. The rot and loss of structural integrity are too great. The rebuilding of the *C. A. Thayer* in a former aircraft hangar in Alameda is testimony to the level of work required on a wooden vessel that had been maintained on a regular basis and kept floating until rehabilitation started. Approximately 90 % of the *C.A. Thayer* hull material is being replaced. The after cabin superstructure on the other hand, is in much better shape due to more concerted efforts to protect and maintain those areas of the ship that were least deteriorated to begin with and easiest to protect.

Wapama is in a precarious structural state and requires some immediate steps to alleviate safety and liability risks as outlined in the Condition Survey. In addition we recommend an aggressive schedule for determining disposition and for funding other required short-term stabilization measures. We must emphasize that this vessel presents a large "sail area" to the wind, and is in potential danger of movement within its lateral supports, which could result in a threat to life safety as well as possible collapse resulting in material coated with lead paint falling into the water.

We have suggested a series of stabilization action items from immediate to one and three year time frames with rough order of magnitude (ROM) budgets based on costs experienced with the *C. A. Thayer* where both D&P and ACR are intimately involved. Budgeting the costs of the various salvage and restoration options listed will be considered in the next phase of the study. It should be understood that any option which does not put the Wapama back in the water, would require land-based exhibit planning and budgeting for a protective structure. The Team is aware of other vessels which are exhibited within structures on land.

We look forward to your review of the attached Exhibits and agreement on a direction for the second phase of the work to determine the ultimate disposition of this important National Historic Landmark.

WAPAMA CONDITION SURVEY



D&P Report No. 2526-001
October 7, 2005

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List of References

A) 1986 *Wapama* Historic Structure Report

B) 1985 Stability Analysis and Condition Survey of Barge 214

Wapama Condition Survey

Background

The vessel *Wapama* (Figure 1) is the last remaining example of the wooden steam-powered schooners, which hauled lumber and passengers along the Pacific Coast. Built in 1915 and registered as a National Historic Landmark (NHL), *Wapama* is constructed of old growth Douglas Fir, and is 216 feet long and approximately 50 feet from keel to house top, with a gross tonnage of 945 GT. In 1979, she was removed from her berth at the California State Historical Maritime Park at Hyde Street Pier and moved to a submarine pen at Hunters Point Naval Shipyard. This move to quiet water was to minimize stress on her hull. Prior to building a breakwater in the mid 1980's, the Hyde Street Pier resembled an ocean pier more than a bay pier. Winter storms, in particular, were extremely stressful on the entire fleet. In 1980, in anticipation of rebuilding *Wapama* in the HMB-1/Crowley Maritime Plan, she was placed upon Barge 214. Since that time she has remained on the barge and received limited maintenance. Currently, she resides atop Barge 214 in a flooded graving dock at the Richmond Reserve Shipyard in Richmond, CA.

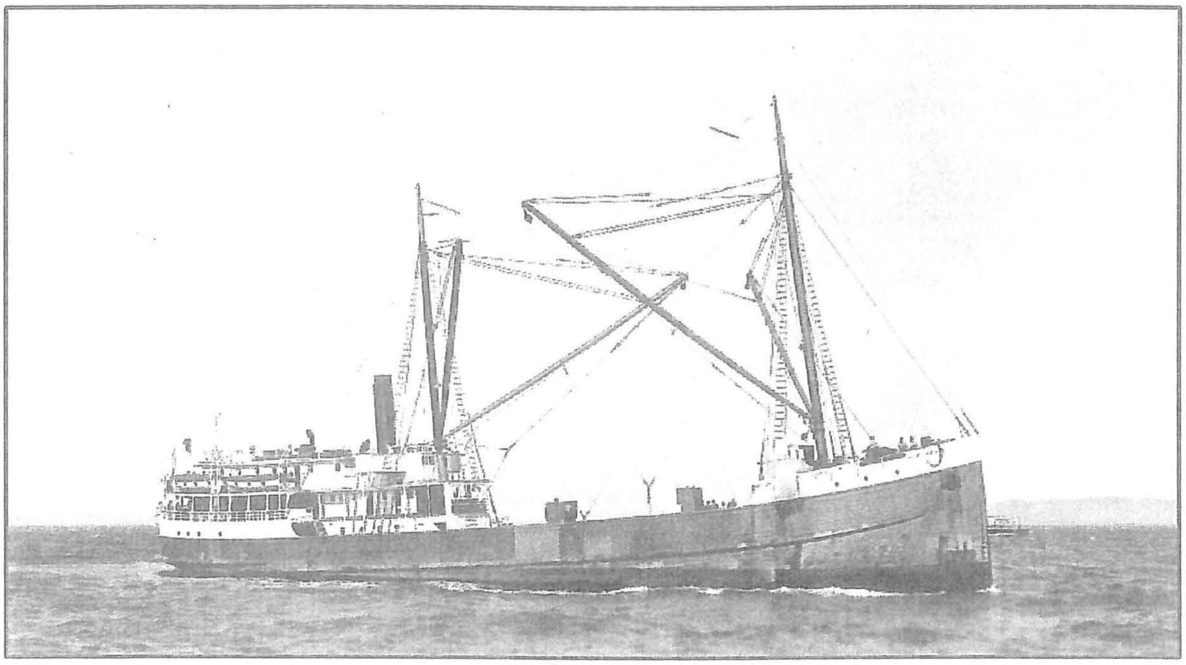

Figure 1 – *Wapama* circa 1935

Scope of Work

In February 2005, BMT Designers & Planners, Inc. (D&P) was tasked as a subcontractor to Architectural Resources Group (ARG) to undertake a condition survey of the vessel and barge and to provide preservation recommendations. The scope of work for D&P included:

- An updated safety and stability determination of the barge and vessel, both separately and in combination.

- An updated structural review of the vessel's main features and support structure.

The results of these tasks are summarized below.

Summary of the Results of the Rapid Structural Survey

During the week of June 20th to the 24th, 2005 an initial rapid structural assessment of the *Wapama* and Barge 214 was undertaken. During this time the vessel and barge were inspected and analyzed for potential safety and stability weaknesses, and areas of actual or potential structural failure were identified. During the rapid structural assessment the 1986 *Wapama* Historic Structure Report (Reference A) and a 1985 Stability Analysis and Condition Survey of Barge 214 (Reference B) were used as a baseline for assessing the vessel and barge's condition.

Barge 214

With respect to Barge 214 the rapid structural survey revealed no significant structural problems, although an upward deck deflection amidships was noted and is believed to have been caused during a reported grounding incident, prior to the barge being acquired for use in supporting the *Wapama*. A visual inspection of the tanks indicated the collection of a small amount of water and other fluids in some of the tanks, as shown in Figure 2. It would be necessary to pump these fluids out of the bilges in order to complete the visual inspection. Regular maintenance and some localized repairs are suggested to replace localized bottom damage.

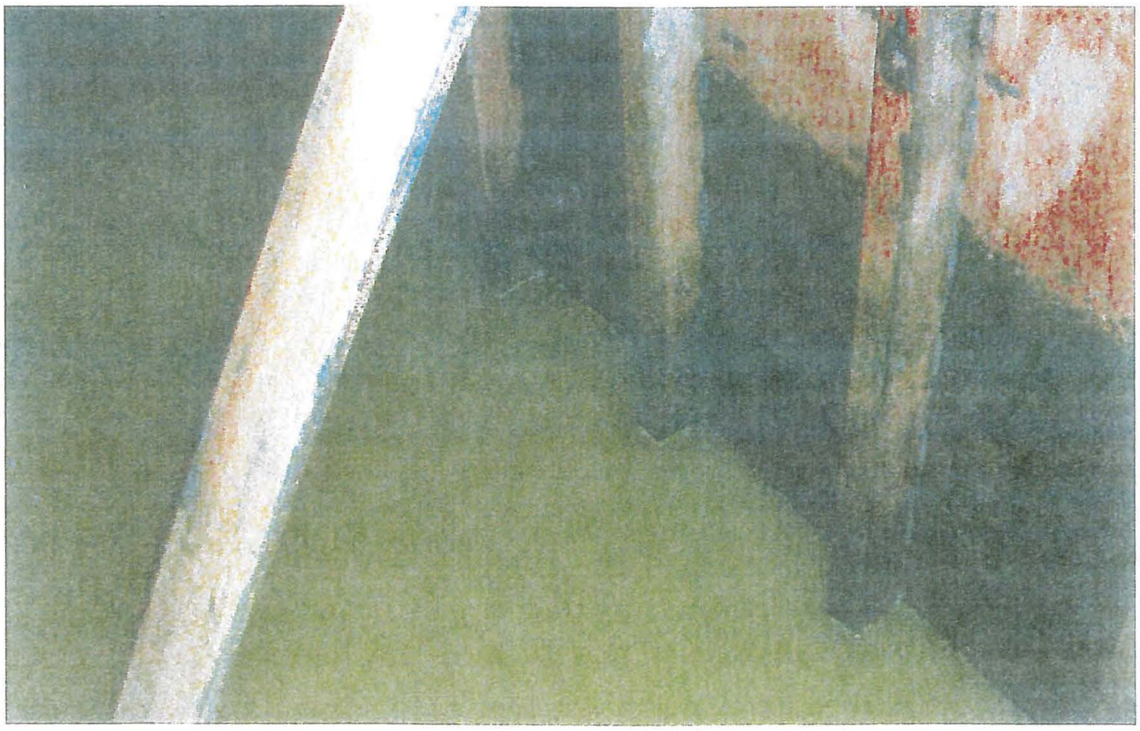

Figure 2 – Example of Fluids in Bilges of Some Tanks on Barge 214

Wapama

With respect to *Wapama* the rapid structural survey revealed that the after superstructure is in relatively good shape, as shown in Figures 3 through 9, though there is some deterioration/damage in way of the Starboard Side Boat Deck, as shown in Figure 10.

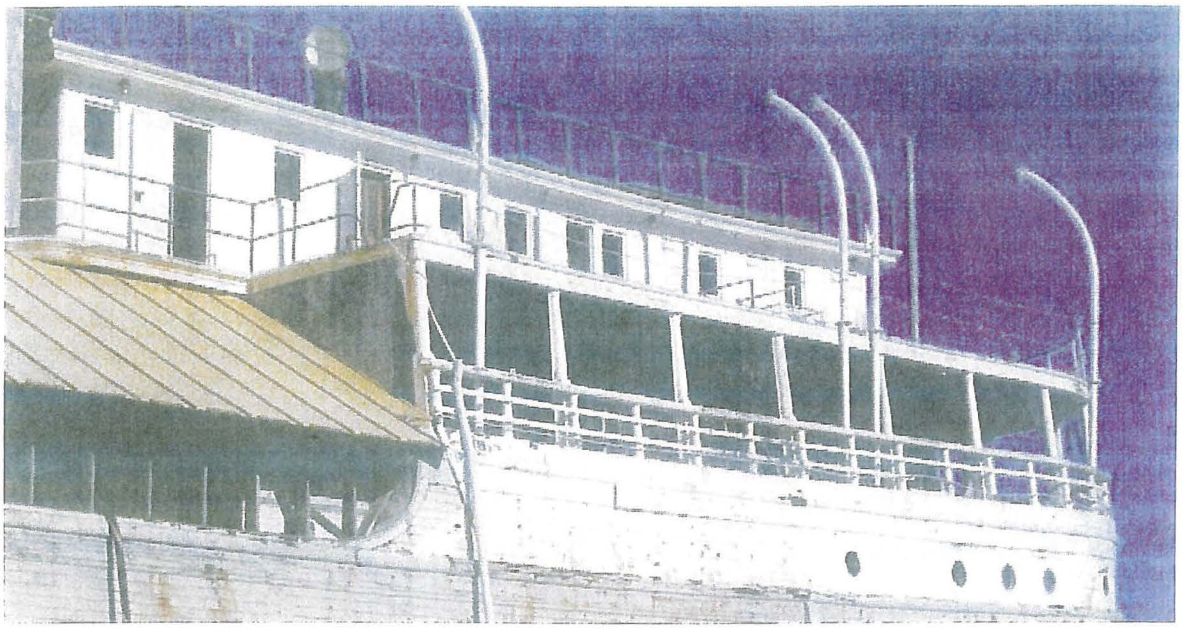

Figure 3 – *Wapama* Superstructure

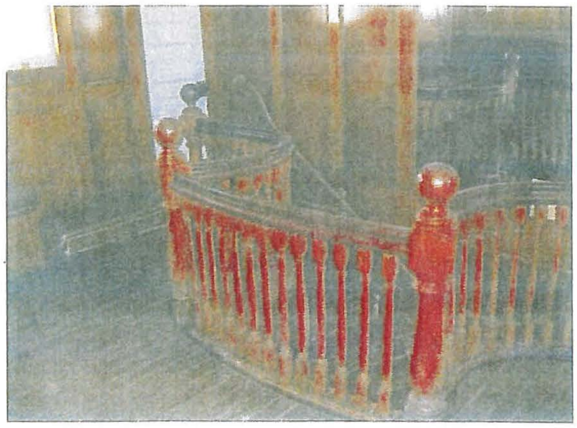

Figure 4 – Social Hall

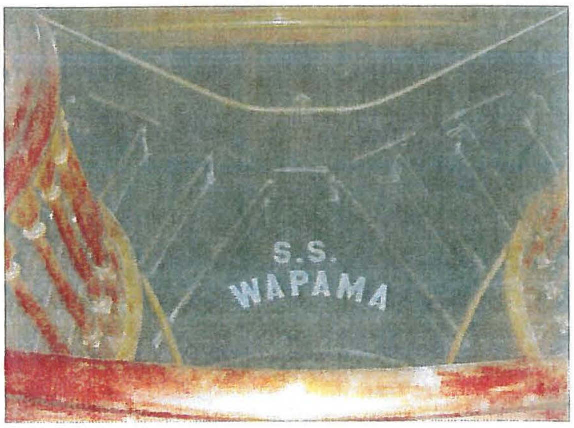

Figure 5 – Main Stairway

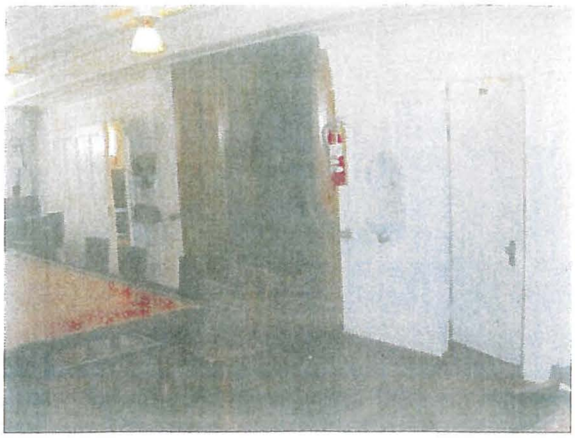

Figure 6 – Dining Salon

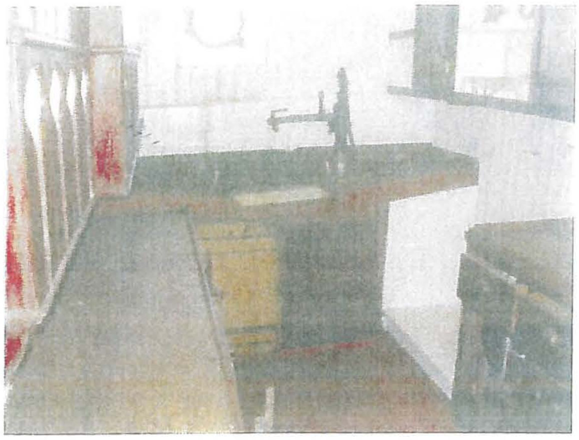

Figure 7 – Pantry

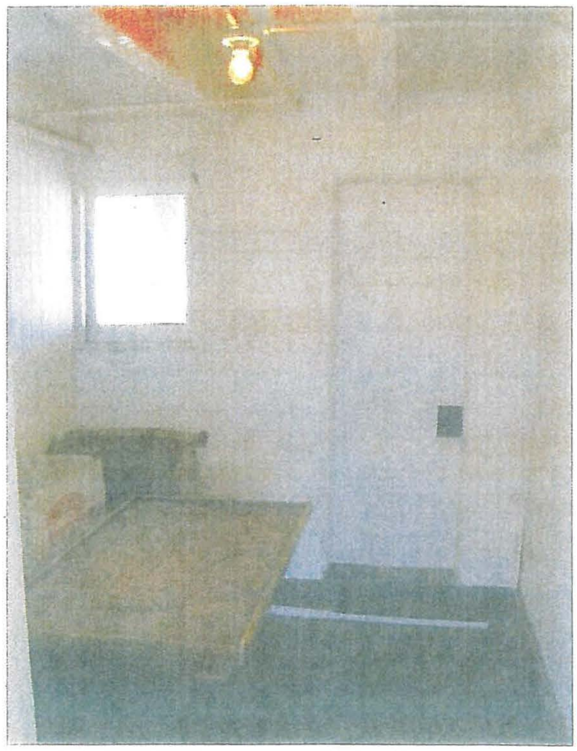

Figure 8 – Smoking Lounge

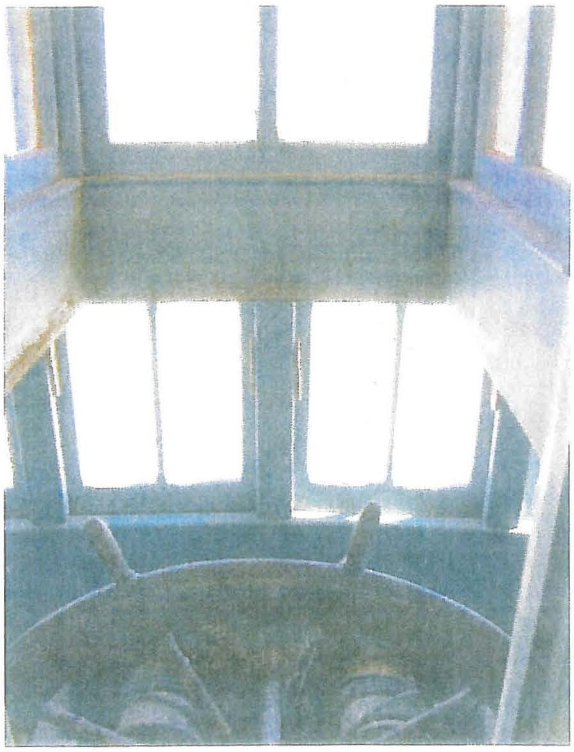

Figure 9 – Wheel House

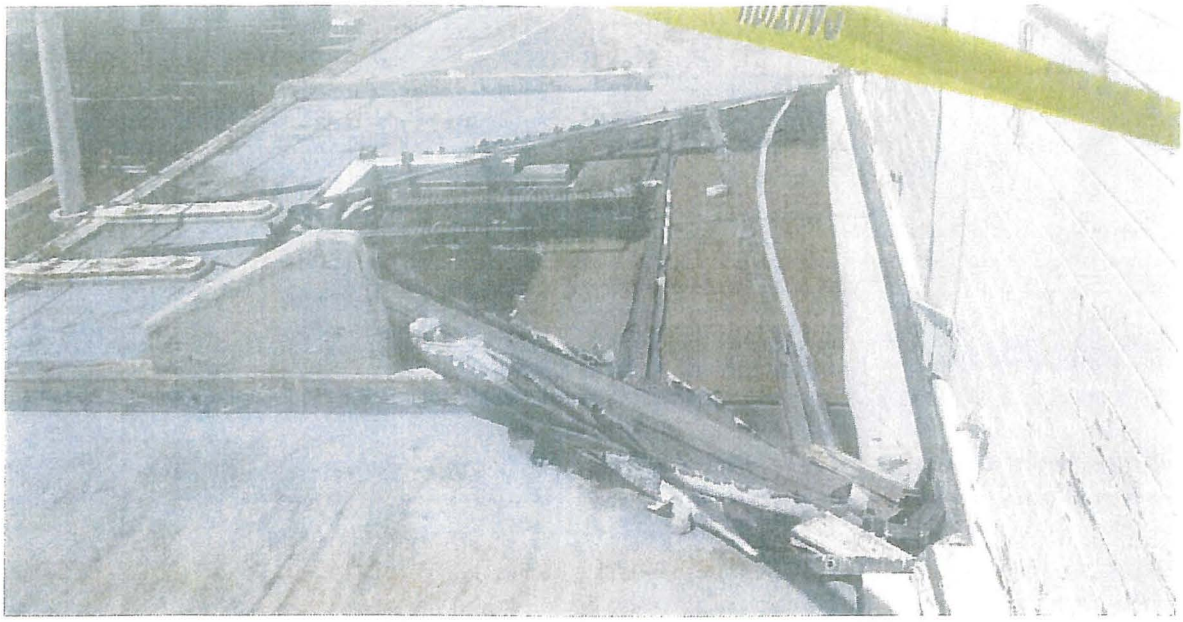

Figure 10 – Deterioration/Damage at the Starboard Side Boat Deck

Overall, the current state of the main deck house shows little change from the condition described in the 1986 Historic Structure Report (HSR). It is noted that this is due in large part to the efforts of the NPS / SAFR maintenance personnel assigned to *Wapama*. This staff, with the help of volunteers, has kept these spaces ventilated while also protecting them from the environment and rainwater seepage. This is in keeping with recommendations that were made in the 1986 HSR.

Although the main machinery space shows significant deterioration of some of the auxiliary machinery, metal gratings, and boilers (as shown in Figures 11, 12, & 13) many of the main machinery components, such as the main engine and generators, are presently in very good shape thanks to some dedicated preservation efforts undertaken by NPS /SAFR staff and volunteers, as shown in Figures 14, 15, & 16).

Figure 11 – Deteriorated Machinery

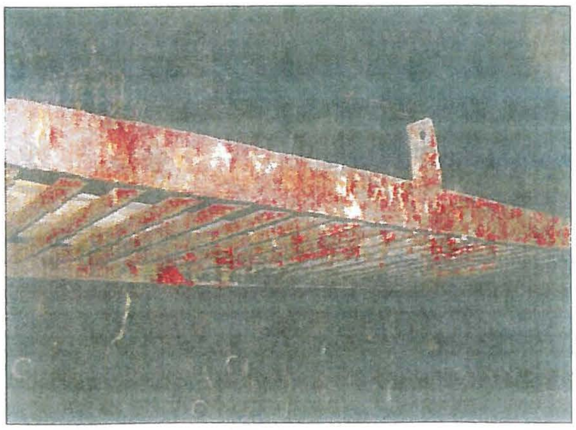

Figure 12 – Deteriorated Grating

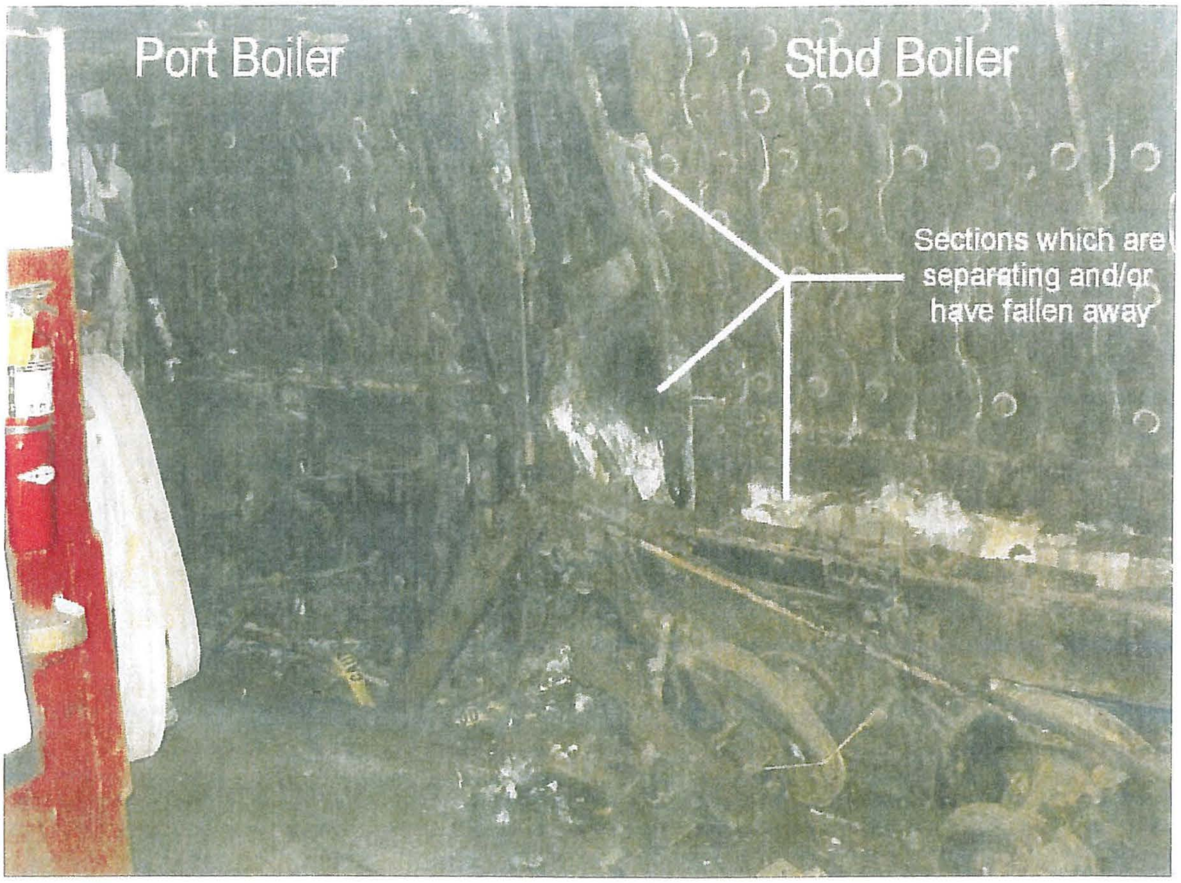

Figure 13 – Current Deteriorated State of Boilers in Engine Room

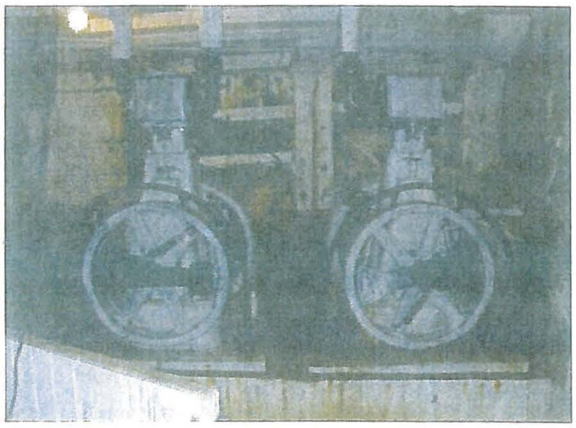

Figure 14 – Generators

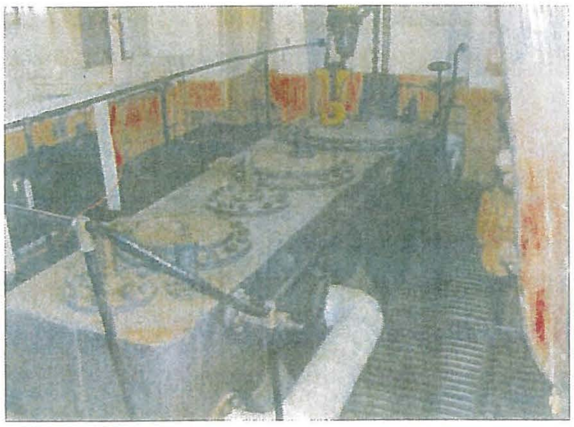

Figure 15 – Main Engine (from above)

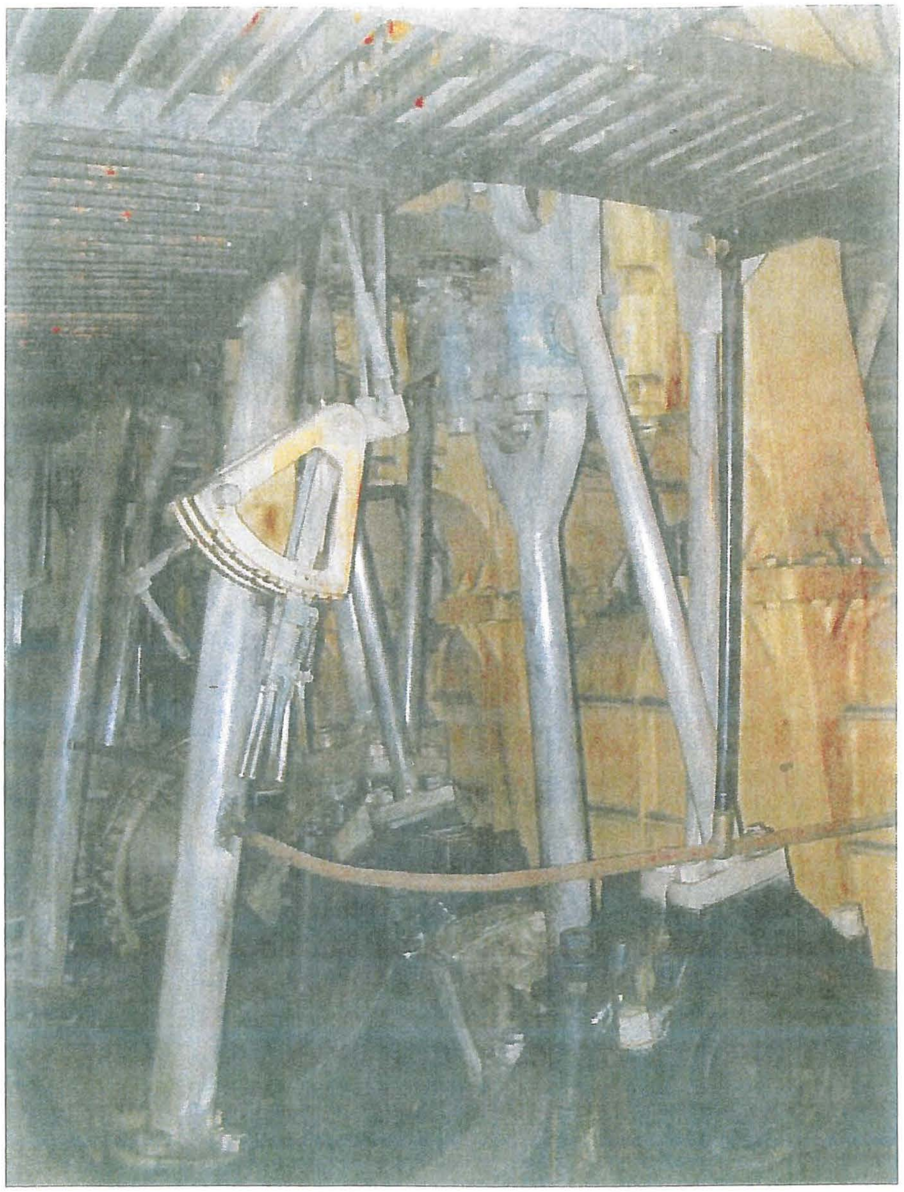

Figure 16 – Main Engine (from below)

The hull and main deck forward, by comparison, were found to be in an extremely deteriorated state. It was not possible to assess the condition of the main hull frames at this time, however the exterior hull planking and sheathing was found to be disintegrating, as shown in Figure 17.

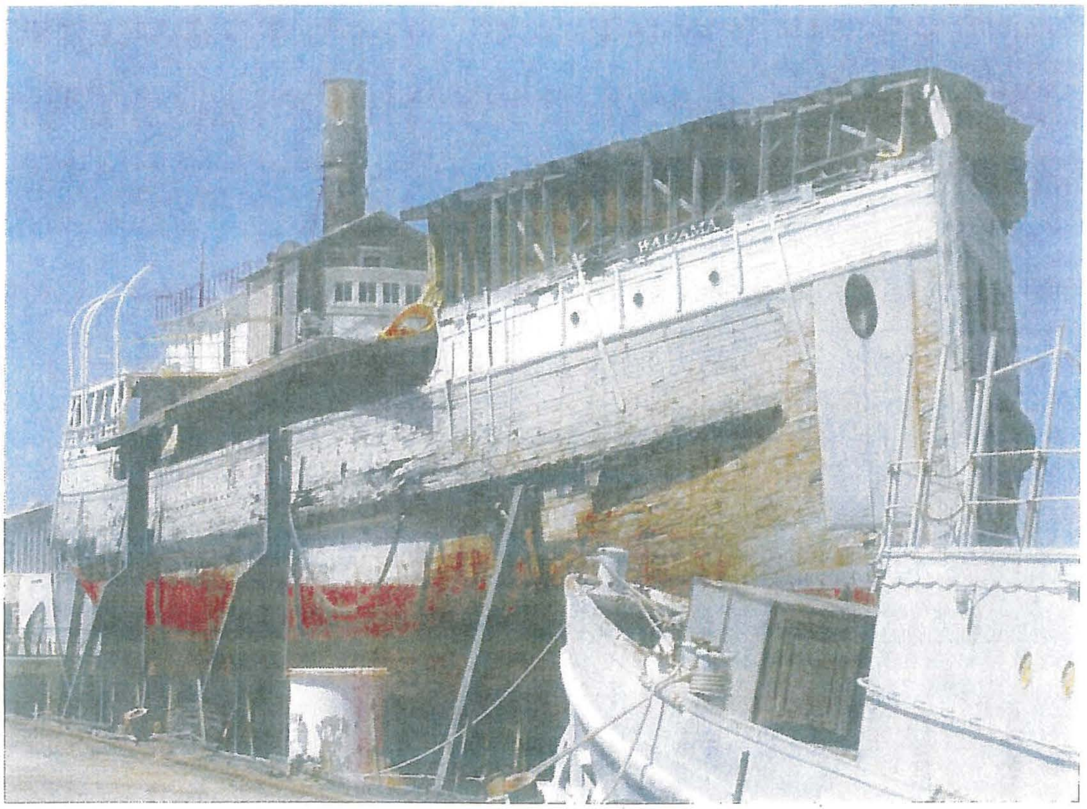

Figure 17 – *Wapama* Current Exterior Condition

It was reported that pieces of rotten wood are continually falling from the vessel, and the NPS / SAFR maintenance individual indicated that these pieces are becoming bigger as time goes on (see Figures 18 and 19).

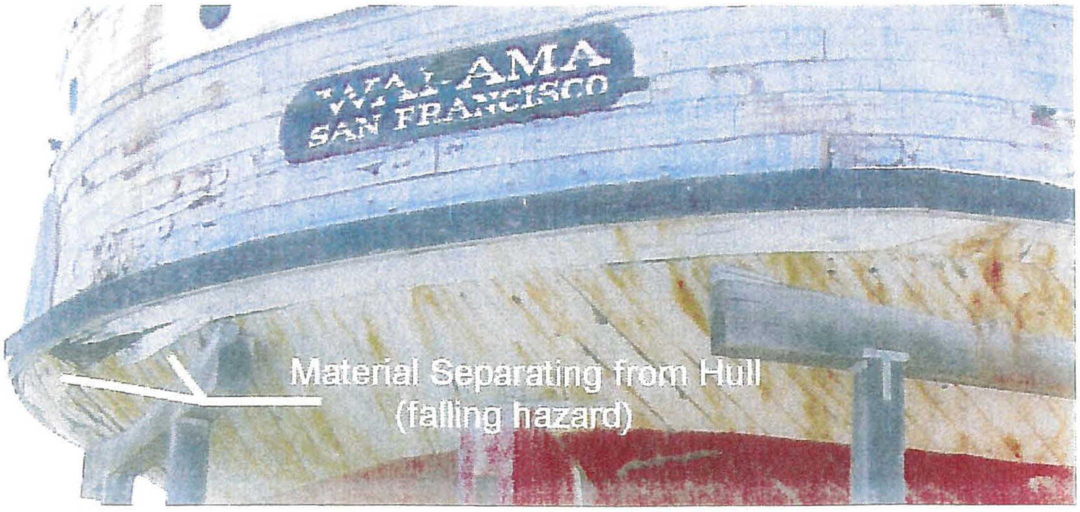

Figure 18 – Deterioration of Aft Rub Rail

Of particular concern from a personnel and vessel/barge safety point of view are the cast iron fairleads and chain plates on the bow. Deterioration of the deck and side hull planking under these fittings, as shown in Figure 20, have left them in a precarious state where they could fall from their current locations, potentially injuring anyone working on the deck below. Due to their weight and size they could also represent a threat to the watertight integrity of the barge if they were to fall from their present locations.

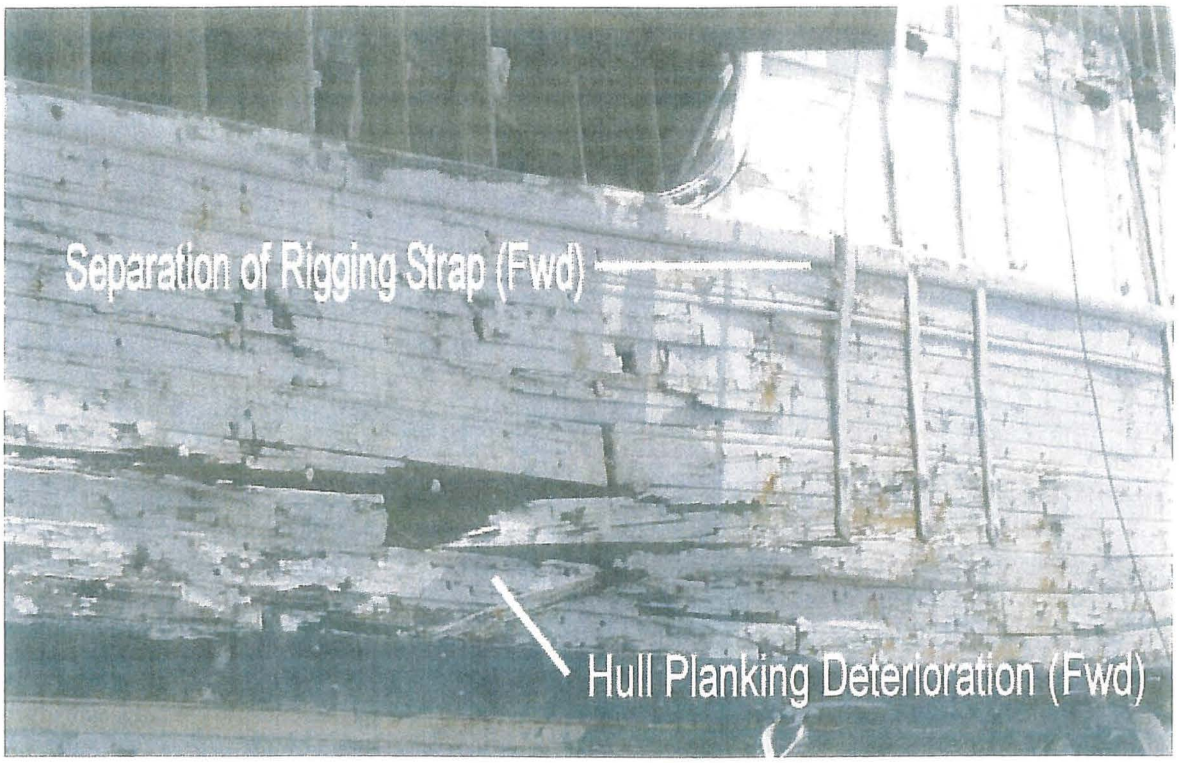
Separation of Rigging Strap (Fwd)
Hull Planking Deterioration (Fwd)

Figure 19 – Deterioration of Hull & Fittings (Fwd)

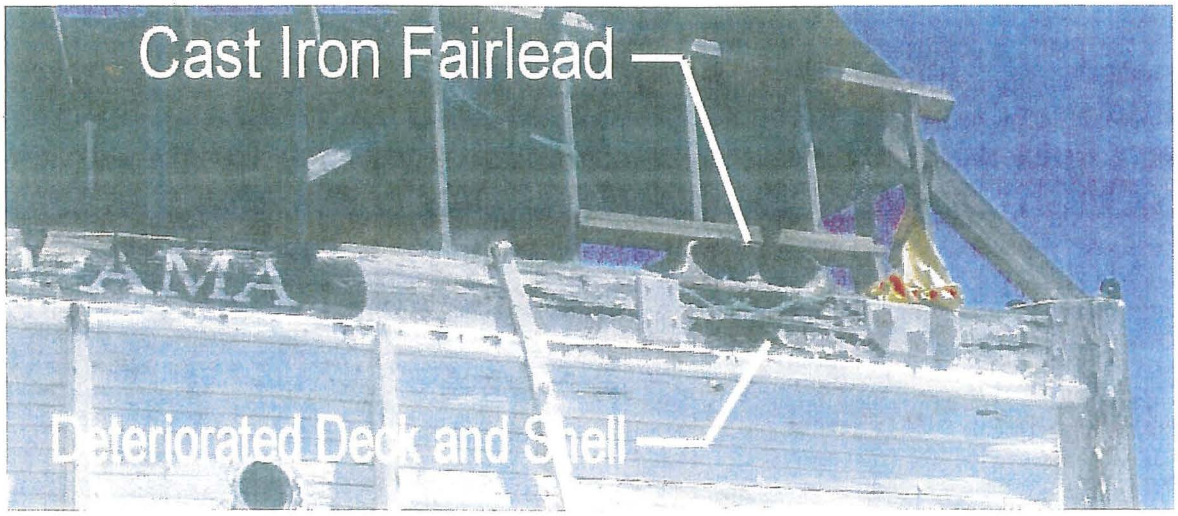

Figure 20 – Deterioration of Deck & Shell at Cast Iron Deck Fittings

Two other safety concerns include the presence of lead based paint and the possibility of structural collapse. If the decision is made to perform major structural rehabilitation or disassembly of the vessel onsite at the Richmond CA site, consideration will have to be given to protecting the surrounding environment from lead-based paint.

Additionally, within the hold, the aft end of the forward Tween deck is currently falling apart, as shown in Figure 25, and the main deck is showing signs of significant deterioration and decay at the forward end of the hatch. Specifically, the main deck stringers exhibit substantial damage and deterioration and the main deck planking exhibits signs of poorly executed repairs from much earlier in her life, as shown in Figures 26 and 27. All these issues contribute to a very perceptible sag in the main deck and main deck stringers of the main hatch opening, as shown in Figure 28. The bulwark planking, frame heads and deck waterway also show signs of major deterioration at various locations along the main deck, as shown in Figure 29. In order to prevent collapse of the vessel due to the deteriorated state of the deck structure extensive shoring was provided within the hold to support the main deck stringers over most of their length, as shown in Figure 30.

Corrective actions must be taken in the near future to avoid potential safety and liability issues. At the time of the initial Rapid Structural Survey the recommendation was made to provide a locking gate on the gangway to keep the public off the barge. As shown in Figure 31 an effort has already been made to implement this recommendation. It is also suggested that temporary vertical netting could help to mitigate material dropping into the bay.

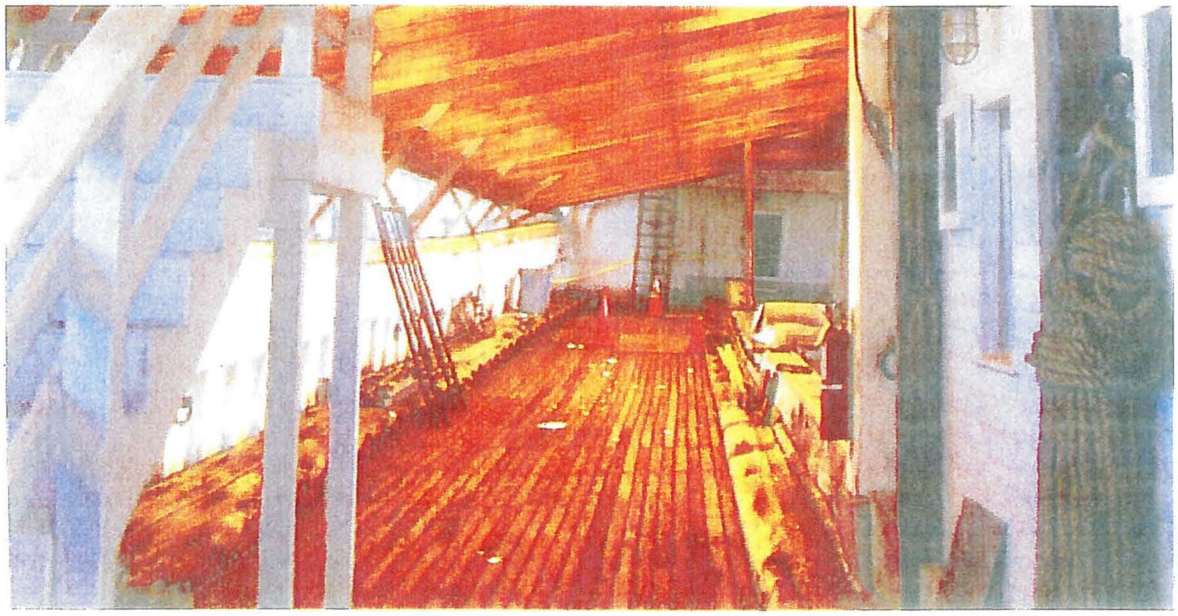

Figure 21 –Main Deck Looking Forward Showing Skew in Bow/Foc'sle

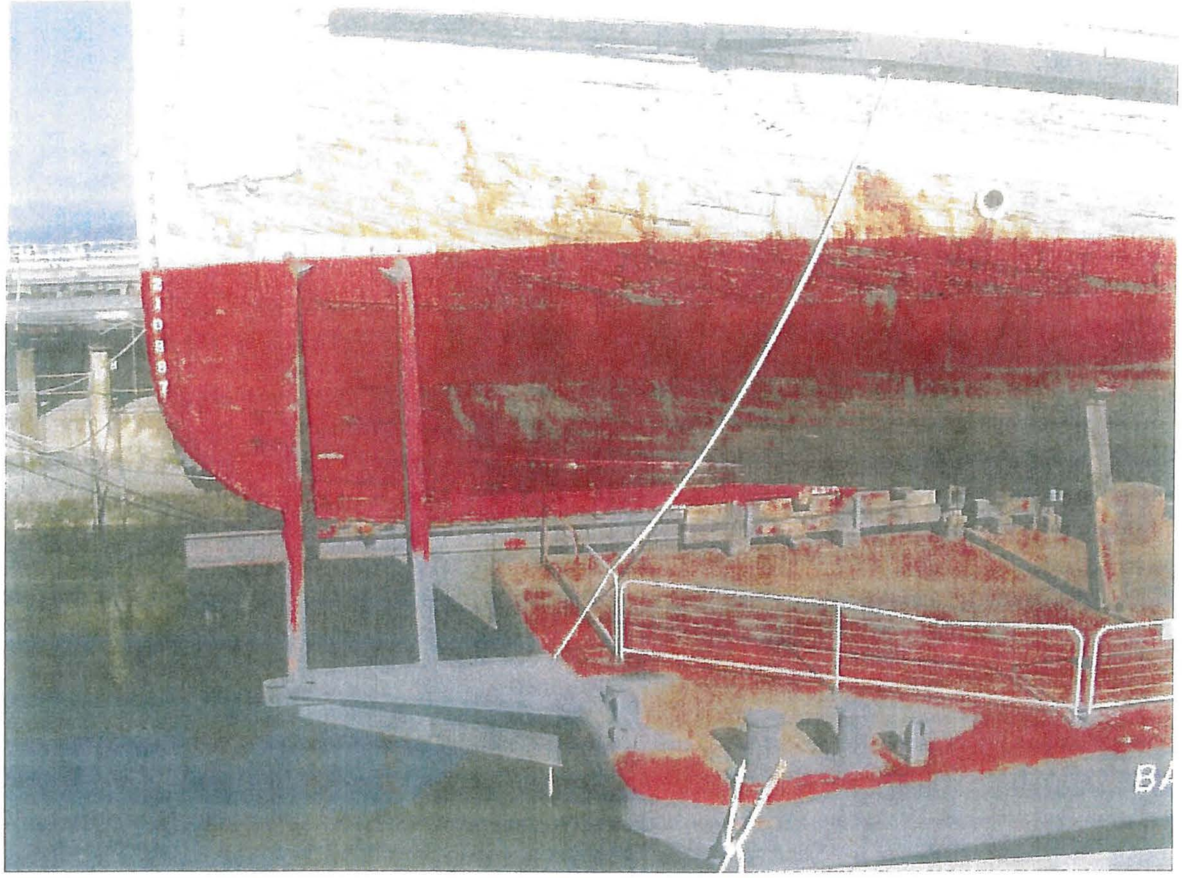

Figure 22 – Bow Overhang with respect to the Barge

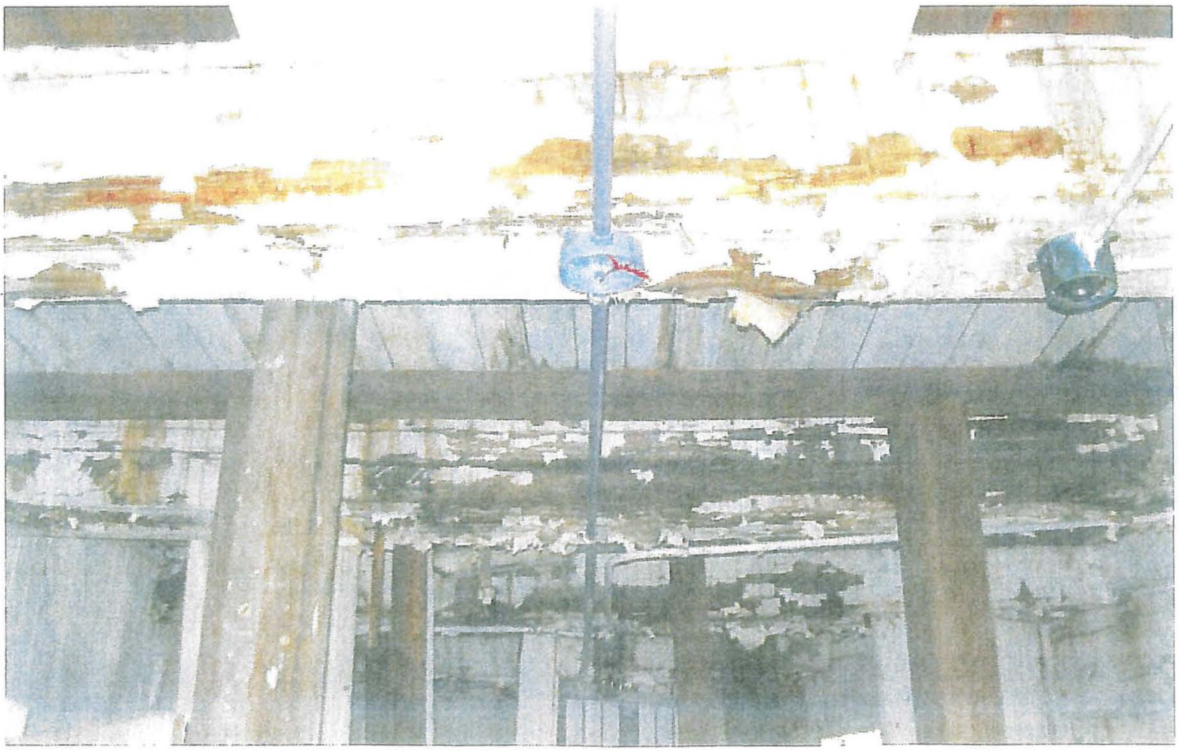

Figure 23 – Deteriorated Deck Structure of the Foc'sle

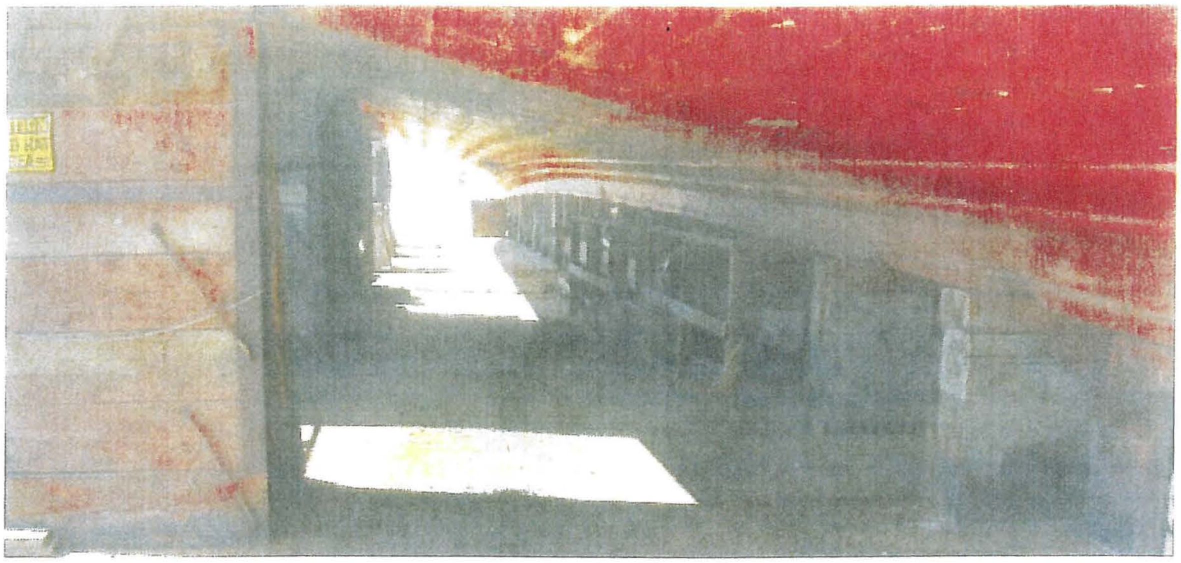

Figure 24 – Keel (looking fwd) Demonstrating Substantial Hog

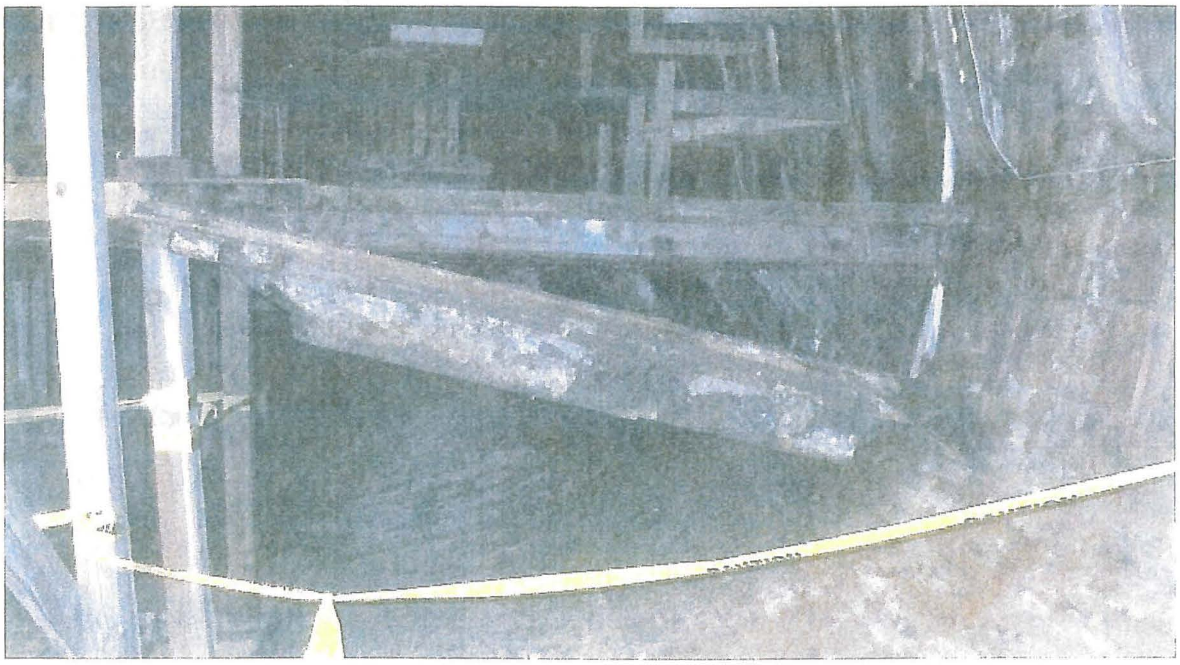

Figure 25 – Collapse of aft end of Forward Tween Deck Supporting Structure within the Main Hold

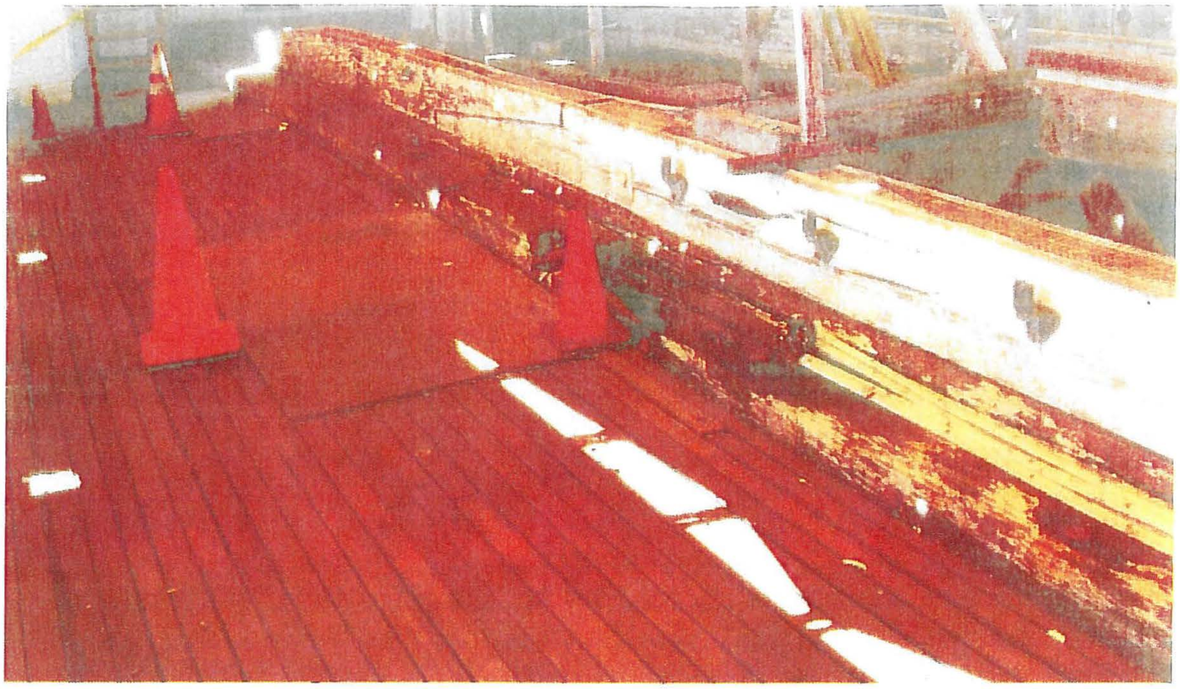

Figure 26 – Deterioration of Main Deck Stringers (Port Side)

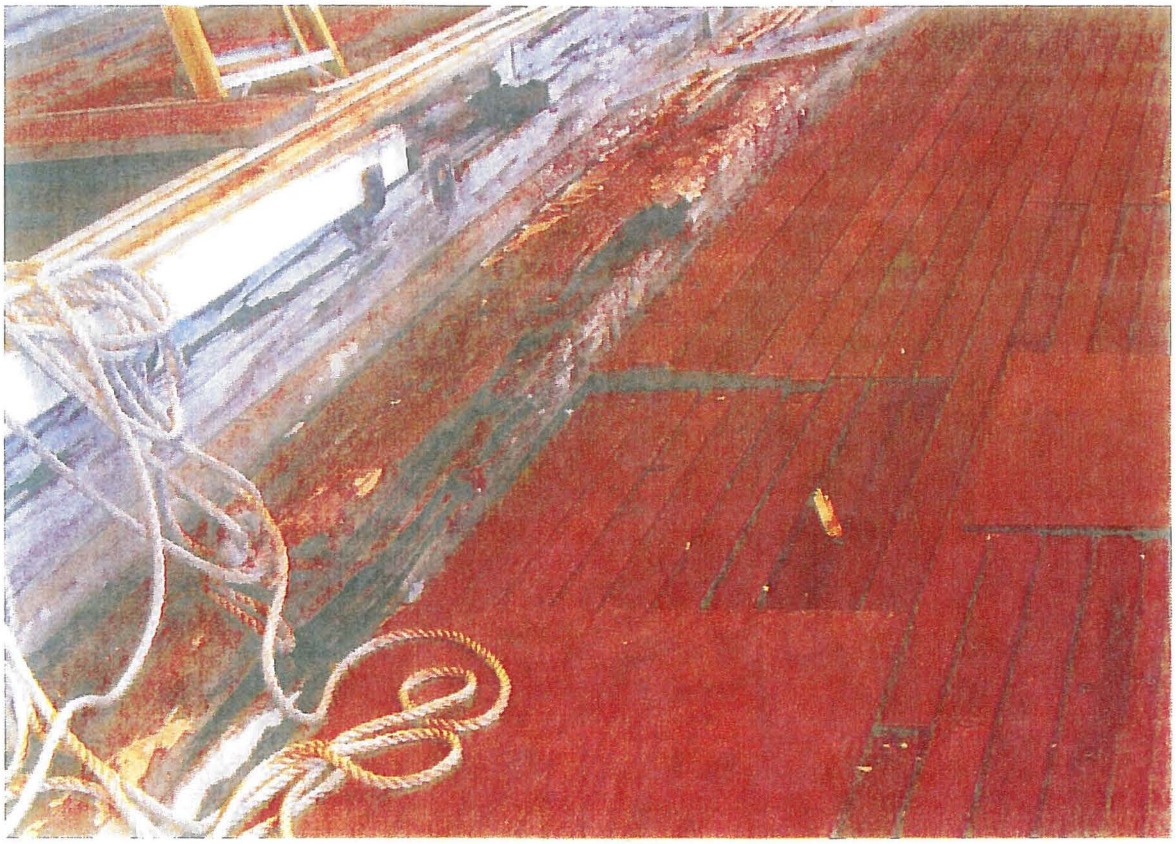

Figure 27 – Deterioration of Main Deck Stringers & Poor Deck Planking Repair (Stbd Side)

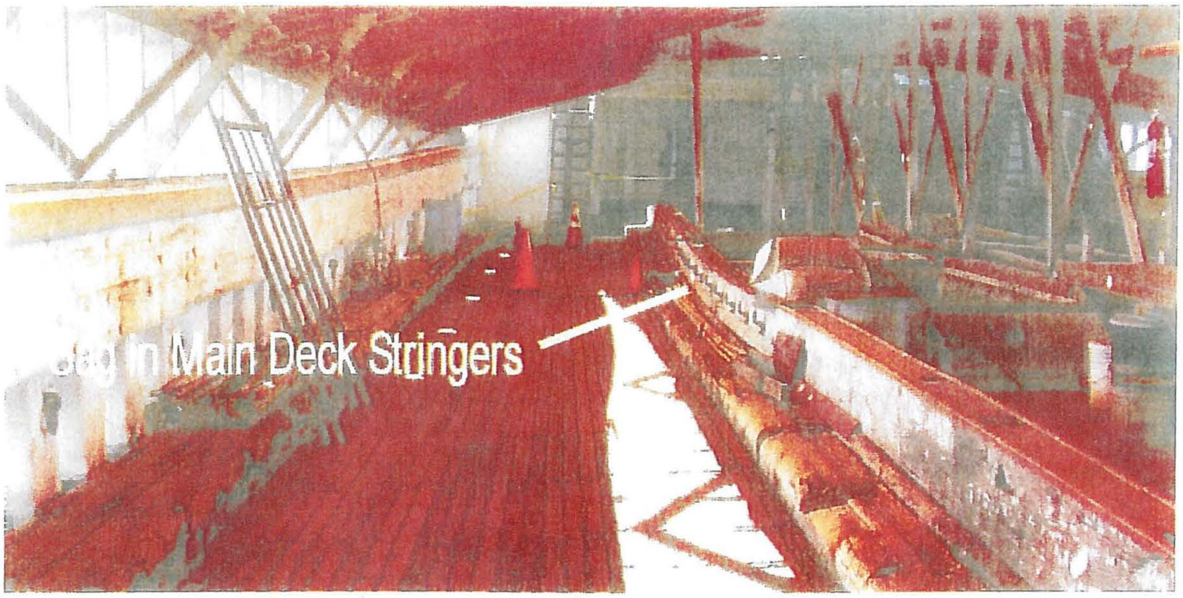

Figure 28 – Sag in Main Deck and Main Deck Stringers next to Hatch Opening

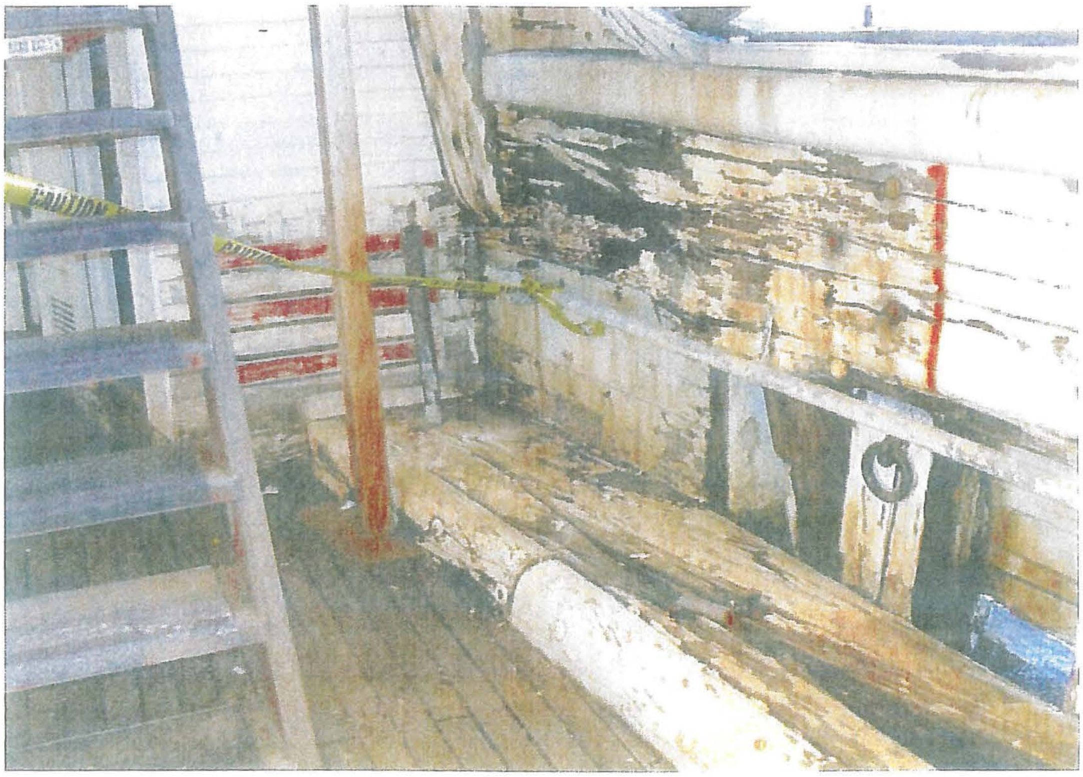

Figure 29 – Deterioration of the Main Deck Bulwark, Frame Heads & Waterway

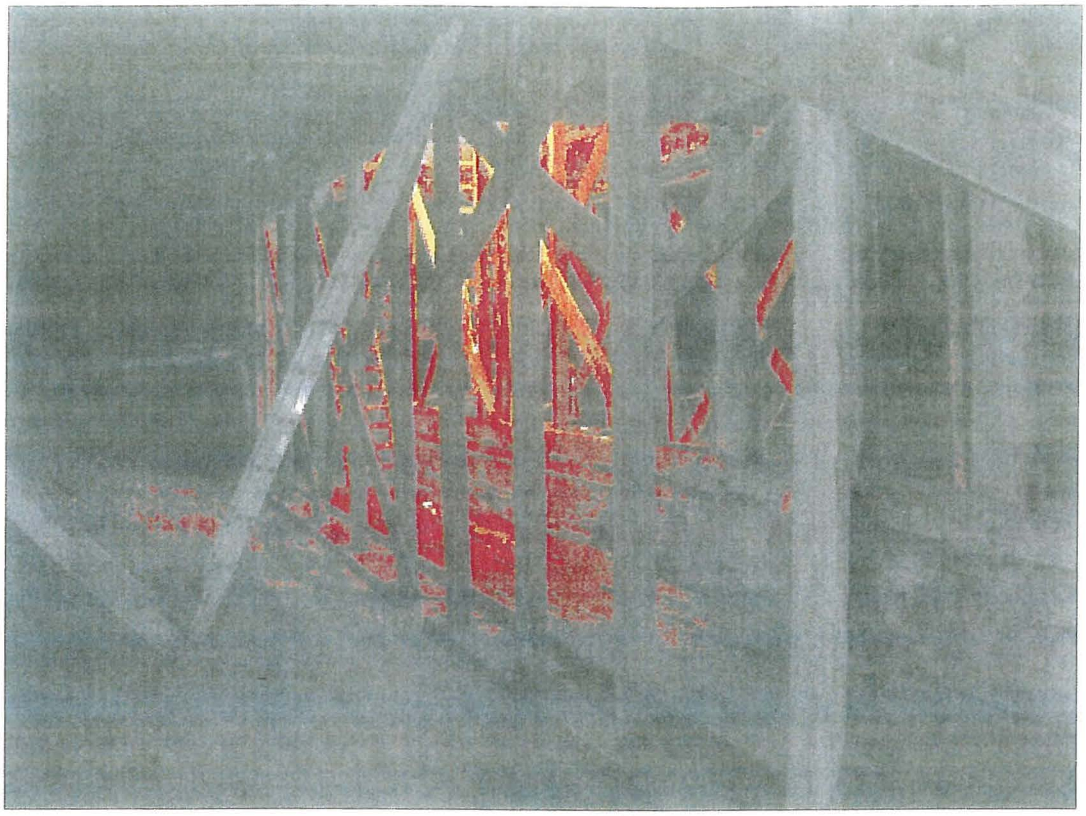

Figure 30 – Shoring within Hold below Deck Stringers

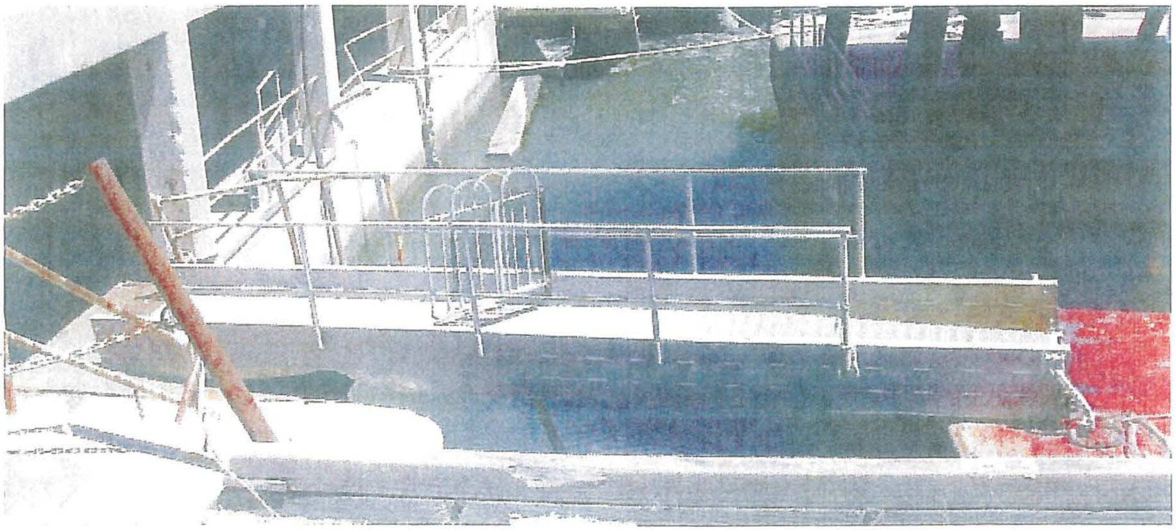

Figure 31 – Current Gangway onto Barge 214

Summary of the Detailed Analysis of the Vessel's Main Features

In order to assist the NPS /SAFR in their decision making process concerning the eventual disposition of the *Wapama,* a more detailed analysis of the vessel's main features was undertaken, with particular focus on the safety and strength aspects of the vessel and stability of the vessel and barge.

Structural Strength and Safety Aspects

Longitudinal Strength

In order to be considered an effective part of a vessel's hull girder, longitudinal strength members are required to run for a minimum of 40% of a vessel's midships length. In her current state, strength members that would normally be included in such an assessment of structural adequacy are broken, rotted and/or distorted in various locations in the forward half of the vessel, bringing the overall longitudinal strength of the vessel into question (see Figures 17, 19, 26, 27, 28, & 29). This damage includes:

- The main deck has lost much of its structure. The deck planking, deck stringers, and waterways all show significant deterioration. A large opening in the deck forward of the main hatch further weakens the deck. As a result, the deck has begun to sag at the hatch, as seen in Figure 28.
- The external hull planking above the waterline has extensive deterioration. In addition to creating a falling hazard, the damaged hull planking is no longer providing longitudinal strength.
- The keel was reportedly broken when *Wapama* was placed on the barge. Figure 24 shows the observable keel hog. As such, the ability of the keel to contribute to the longitudinal strength of the vessel is brought into question and expected to be greatly reduced.
- The ceiling planking, rider keelsons, and assistant keelsons are the primary members contributing to longitudinal strength. The visible surface of the ceiling planking appears to be in relatively good condition. There is evidence of some deterioration from dripping water at the aft end of the hatch opening as shown in Figure 32. This damage dates from the active days as a seagoing vessel. Experience with *C.A. Thayer* suggests that the inner surface of the ceiling planking, at the frames, is likely deteriorated.

The hog of the keel and sag of the deck are indicators that the vessel is settling down on itself, particularly in the mid and forward sections. Although hog on this type of cargo carrying vessel is typical due to increased midships section buoyancy and fore and aft loading in excess of the available buoyancy at those locations, it is not borne out on deck where considerable sag and distortion can be seen. This dichotomy indicates that the hull's topsides and deck have rotted away and are settling in to the more stable lower frames, bottom planking, and lower ceiling.

Figure 33 shows a midship section for the *Wapama* identifying the main structural elements that contribute to longitudinal strength. The effectiveness of each member has been evaluated using the factors discussed above. Using the data provided in Figures 33 and 34, an estimated section modulus of the vessel in its current state has been calculated and has been compared to the estimated section modulus of the ship when she was originally built[1]. The results of these calculations indicate that in her current state the Wapama retains just over 50% of her original longitudinal structural material in the midships section and less than 37% of her original section modulus. Also shown in Figure 33 are three specific areas of interest for further analysis. Due to concerns about the adequacy of the remaining ship's structure, in the next phase of study a more in depth assessment of the structural properties of the hull material in way of these locations, particularly between Frames 13 and 20 (at the aft end of the foc'sle deck), is recommended.

Since *Wapama* is configured with a hatch for loading lumber close to the midships the section modulus was likely minimal when the vessel was first built. The heavy longitudinal deck stringers indicate the builders concern for longitudinal strength and resistance to hogging. An estimated 60% reduction in section modulus is therefore significant. The internal shoring below the deck stringers is possibly assisting in resisting longitudinal bending.

These indicators, along with the knowledge gained with regard to hidden rot from past restoration efforts, lead to a bleak picture for at least the outer and forward portions of the *Wapama* and quite likely much of the aft hull portion of the vessel as well.

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[1] An important step in routine ship design is the calculation of midship section modulus. It indicates the bending strength properties of the primary hull structure. The standard calculation is described in ABS (1987a), Section 6: "The section modulus to the deck or bottom is obtained by dividing the moment of inertia by the distance to the neutral axis to the molded deck line at side or to the base line, respectively."

In general the following items may be included in the calculation of section modulus, provided they are continuous or effectively developed.

- Deck plating (strength deck or other effective deck)
- Shell and inner bottom plating
- Deck and bottom girders
- Plating and longitudinal stiffeners of longitudinal bulkheads
- All longitudinals of decks, sides, bottom and inner bottom
- Continuous longitudinal hatch openings"

The designation of which members should be considered as effective is subject to difference of opinion. The members of the hull girder of a ship in a seaway are stressed alternatively in tension and compression. In general, however, only members which are effective in both tension and compression are assumed to act as part of the hull girder.

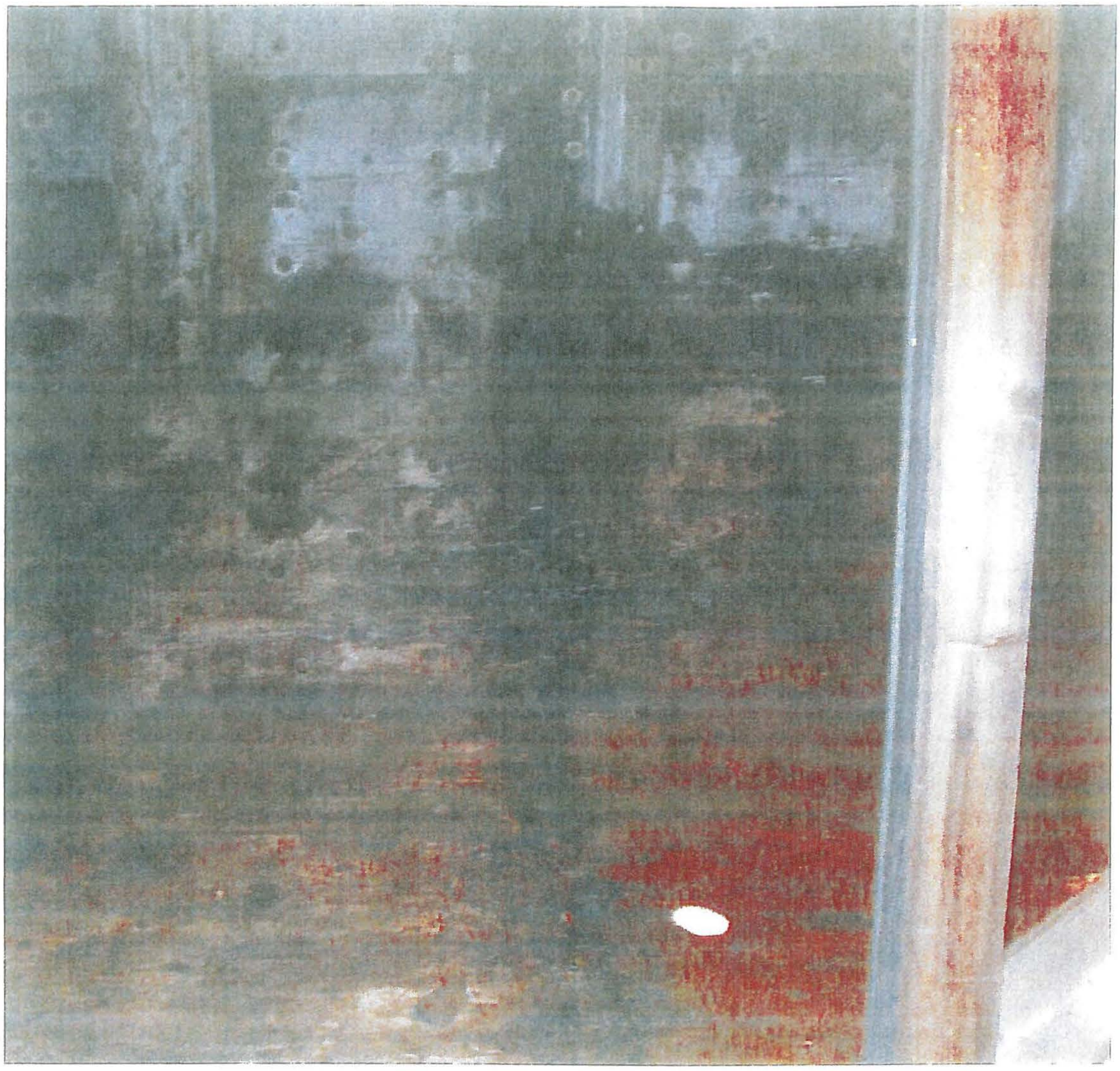
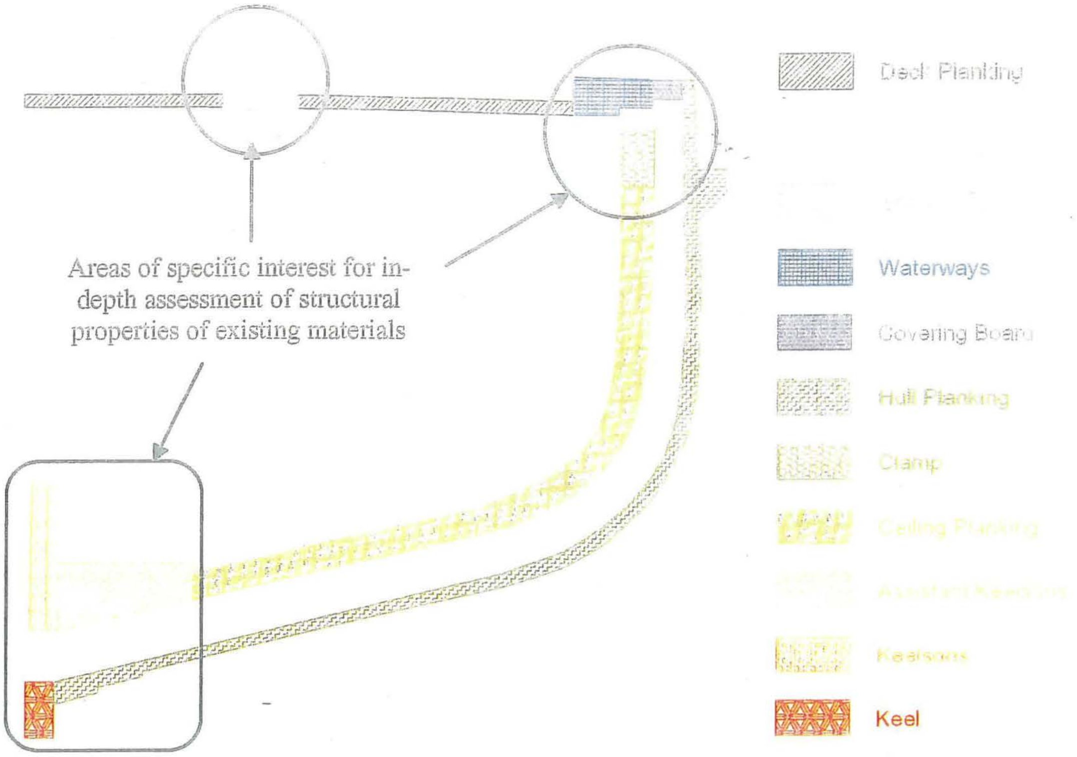


Figure 32 – Deterioration of Ceiling Planking below Aft End of Hatch Opening

Torsional Strength

As previously noted, the current overall state of the main frames is not known. The tops of these frames in many locations show signs of deterioration, as shown in Figure 34. Based on experience with the *C.A Thayer*, it is expected that many of these frames will have suffered significant deterioration at least to the turn of the bilge. This, combined with the deteriorated state of the main deck and hull planking, and the reported damage to the vessel's keel, have contributed to the bow of the vessel twisting to the starboard (when viewed from astern), as was shown in Figure 21. Attempting to prevent this is made more difficult with the bow hanging over the forward part of the barge, as shown in figure 22.

Because of the extent of deterioration, there is little remaining viable structure to arrest this twist in the hull. Under adverse environmental conditions, the bow could separate from the rest of the vessel.



Areas of specific interest for in-depth assessment of structural properties of existing materials

Figure 33 – Midship Section Showing Longitudinal Strength Members

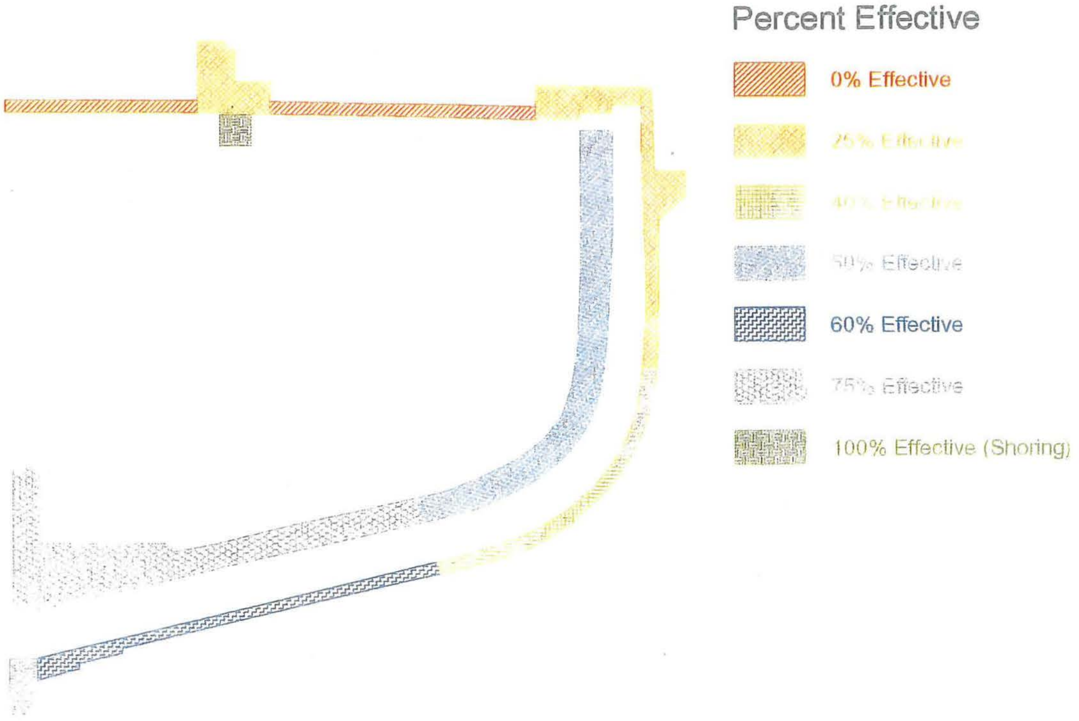


Figure 34 – Midship Section Showing Effectiveness of Longitudinal Members

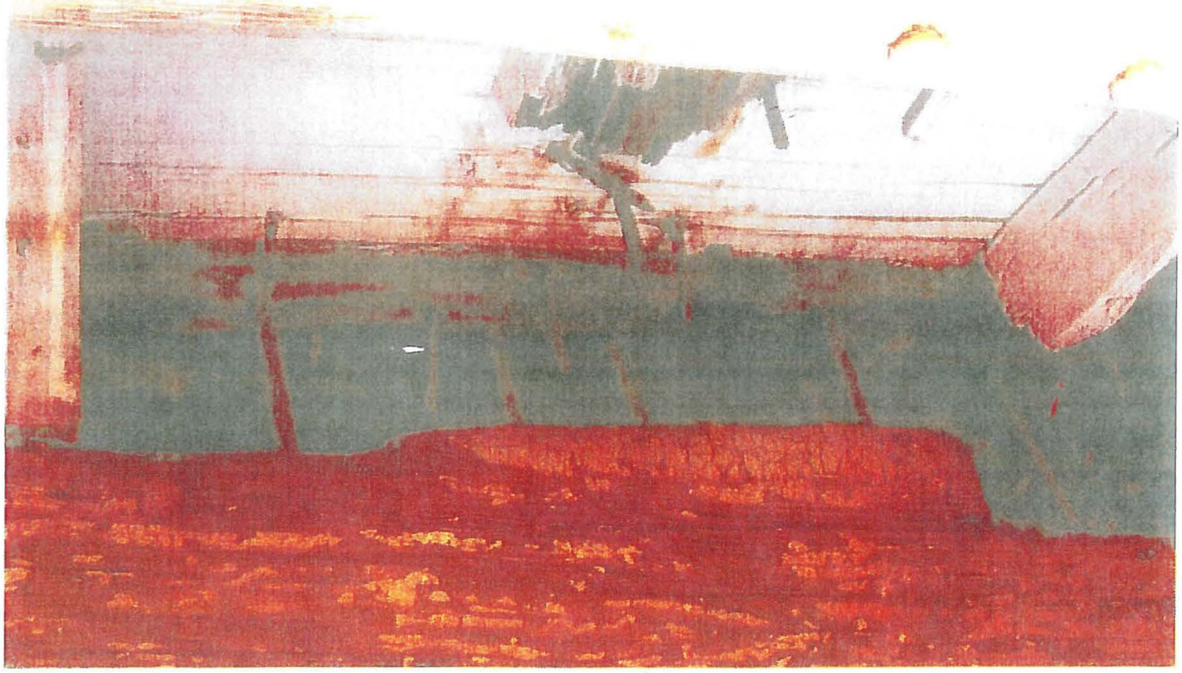


Figure 35 – Wasted Waterway and Frame Tops @ Main Deck Level

Additional Structural Concerns

The current condition of the *Wapama* is troubling and presents a very real dilemma with respect to safety. There are some obvious hazards that can be quickly observed from the pier, from the deck of the barge, and from the deck of the vessel. Figures 18, 19, and 20 illustrate the potential for falling objects. The Foc'sle deck and Tween deck are clearly in danger of collapse, and were previously deemed suspect since equipment (winches, etc.) were removed from them and shoring added to stabilize them.

Shoring supports have been added throughout the vessel where structural members have deteriorated. In many places, this shoring appears to have saved regions from collapse. Significant shoring exists at the following locations:

- External shoring along the hull planking is providing transverse support to keep the *Wapama* in position onboard the barge. Shoring has been added to the bow area, as seen in Figure 22, to prevent this section from continuing to twist in relationship to the rest of the vessel. The deteriorating hull planking remains the weak point to any external shoring scheme. A likely catastrophic failure could be the hull planking collapsing around the external supports, ultimately allowing the bow to separate from the midbody.
- Shoring under the foc'sle deck appears to be carrying the load of this deck. The structural members show significant deterioration, and without the shoring this deck would likely have collapsed long ago.
- Shoring in the hold is supporting much of the main deck. As previously mentioned, much of the longitudinal strength in the deck is no longer effective and the shoring is possibly taking some of the longitudinal load. The shoring is undoubtedly preventing the deck from collapsing into the hold.

As such, the strength and rigidity of the hull to withstand the ravages of time and weather (wind, rain, and sun) and its own weight for many more months are definitely brought into question. How much longer are the deck beams likely to hold up the Main deck, Foc'sle deck, or Tween deck? How much longer can we expect the bow section to stay in place and not collapse or simply fall off? If not for the added internal wood bracing (shoring) in the hold the main deck may have collapsed into the hold long ago. If not for the additional steel supports and poppets (shoring) the bow may have already twisted and fallen off. Each of these remedies has had their effect in stabilizing the structure and are now carrying the lion's share of the load. How much longer can *Wapama*'s rotten structure hold out from falling around the stronger fixes that support it? From a safety view point the answer is simple; they cannot be expected to last any longer and actions need to be taken before a major catastrophe takes place.

Stability Aspects:

A stability analysis of the barge itself, as well as the barge with the vessel onboard has been conducted. In this analysis the intact stability characteristics of the barge were investigated to ensure that the barge could transport the *Wapama* in protected waters, in the event that a decision is made to transport the vessel from Pt. Richmond to a new location.

In general the results of this analysis are similar to the results of a previous stability analysis of *Wapama* and Barge 214 conducted by Hull and Cargo Surveyors Inc. described in Reference 2. Specifically, Barge 214 has adequate intact stability to support the vessel in her current protected location. From a damaged stability point of view, the worst-case condition is when the tank between frames 3 and 11 is flooded. Here, due in part to the added weight of the bow support structure, which appears to have been added to Barge 214 since the 1985 stability analysis, the forward trim that the barge would take on with the tank between frames 3 and 11 flooded, is enough to immerse the forward edge of the deck.

If the forward edge of the deck of the barge were to become immersed due to damage during towing, the loss in waterplane and righting energy could result in capsize or plunging of the barge in a seaway. To mitigate this, it is recommended that the forward tanks of the barge be pumped dry and ballast weight be added aft on the barge. Calculations indicate that in her current condition a weight of ballast between 80 to 130 long tons would be sufficient to provide for adequate margin to prevent the forward deck edge from becoming immersed in the event of damage forward.

If significant alterations were made to the vessel and barge, such as the addition of additional shoring, or the removal of the winches and other heavy pieces of deck machinery and fittings, then a further review of the damage stability characteristics of the barge and vessel would be warranted at that time.

Should the decision be made to disassemble all or part of the vessel in place onboard the barge, a careful analysis will have to be prepared, concurrent with disassembly, to ensure that adequate stability and trim characteristics are maintained throughout the process. This may necessitate either ballasting the barge or providing counter weights on deck to accommodate the reduction in weight as the bow section is disassembled, preventing the barge from taking on an unsafe amount of heel or trim during the disassembly process.

If the decision is made to move *Wapama* while on the barge, a further study of the towing limits must be investigated. An analysis of the limiting states of roll and pitch will be conducted for Phase II

Actions

The SOW requests the contractor recommend actions to be taken to maintain a level of life safety for personnel on Barge #214 and *Wapama*. The following are the condition survey team's recommendations with respect to life safety.

Items requiring immediate action (at a ROM cost of $11K)

> Falling objects (deck fittings, chain plates, rub rail, etc.) are the most observable and prevalent danger. These objects should be catalogued, removed from the vessel, and stored for restoration.
>
> Falling wood should be removed and disposed of. It should be noted that some of this wood may contain hazardous materials and coatings (such as lead based paint), which will require special handling and disposal.
>
> Restrict access to the deck of the barge by installation of a locking gate on the brow. This effort has been started based upon the team's earlier verbal recommendations made after the first condition survey.
>
> Restrict access to the forward half of the vessel by signs and barriers. The condition of this portion of *Wapama* is precarious for the general public, as well as staff, and should be treated with extreme caution.
>
> Post areas where asbestos is present and clean-up fuel oil spills.

Items requiring action within 1 Year (at a ROM cost of $321K)

> Remove concentrated weight items from the deck and topsides (winches, excess paints, tar, oil, etc.). These objects should be catalogued, removed from the vessel, and then stored for restoration. Parts of the vessel deemed of historical interest and in a suitable condition for storage should be kept for interpretive uses.
>
> Remove hazardous materials (asbestos, and fuel oil). Wood with lead based paint as removed from the vessel for safety should be handled and disposed of with caution.
>
> Documentation of *Wapama* by laser survey and digital photography is recommended for the entire vessel's internal and external shape and the location of fitting and equipment on board. A check should be completed to ensure scantlings values match those recorded in the drawings.
>
> Stabilization of the aft portion of the vessel's hull and decks to include support of the stern overhang and upper decks.
>
> Continuous maintenance geared toward maintaining the ventilation and exclusion of rainwater from the aft cabins, engine room, etc.

Items requiring action within 3 Years (at a ROM cost of $2.5M)

> Begin systematic and careful disassembly of the forward section of the vessel, from the pilothouse to the bow. Parts of the vessel deemed of historical interest and in suitable condition for storage should be kept for restoration.
>
> Remove aft portion of the vessel from the barge and place under cover for restoration and rehabilitation based upon the option chosen by NPS / SAFR.

Recommendations and Conclusions

Due to her historical significance, our recommendation is to save the *Wapama* for display at the SAFR Park in some yet to be chosen format. Due to the severely deteriorated state of the structure in the forward half of the ship, there is likely little within that section of the ship that can be salvaged for re-use with the potential exception of some of the hanging knees within the cargo hold and the forward hatch beam with the registry number carved into it. Additionally, the severely deteriorated state of the structure in the forward half of the ship is an immediate safety concern that must be addressed in the very near term.

It is recommended that within the next six months, items that represent an immediate threat of falling, such as the cast iron deck fittings, chain plates, rub rails, etc. should be cataloged and removed from the vessel so that they can be stored for restoration. Any loose or falling wood should also be removed and properly disposed of, which may require special handling because of the presence of asbestos, fuel oil, lead based paints, and other potentially hazardous coatings Also, a lock should be provided for the gate on the brow to restrict access to the deck of the barge. Access to the forward portion of the vessel should also be restricted by means of signs and barriers.

Within one year concentrated weight items such as winches and the excess paint and tar buckets currently onboard the vessel should be cataloged, removed, and stored for later interpretive uses. Documentation of *Wapama* by laser survey, and digital photography would also be recommended at this time for the entire vessel's internal and external shape and the location of fitting and equipment on board. Stabilization of the aft portion of the vessel to include support of the stern overhang and upper decks should also be undertaken. Additionally continuous maintenance geared toward maintaining the ventilation and exclusion of rainwater from the aft cabins, engine room, should also be accomplished.

Finally within the three-year time frame it is strongly recommended that work be initiated on the systematic and careful disassembly of the forward section of the vessel, from the pilothouse to the bow. Parts of the vessel deemed of historical interest (such as the forward hatch beam which has the vessel's official number and gross tonnage measurement inscribed on it) or in suitable condition for re-use (such as some of the hanging knees) should be kept for restoration. Upon completion of that work the aft portion of the vessel could then be removed from the barge and relocated to a covered facility for any restoration and rehabilitation work that may be considered.

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SECTION 1

REPORT SUMMARY

REPORT SUMMARY

INTRODUCTION

Winzler & Kelly Consulting Engineers performed a limited Hazardous Materials Survey of the Steam Schooner S.S. Wapama (Wapama) a National Historic Landmark (NHL) vessel that is located on floating Barge 214 in a flooded graving dock at the Richmond Reserve Shipyard, Richmond, CA. The purpose of this investigation was to screen for asbestos, lead and/or other potentially hazardous waste materials which could present environmental hazards during planned maintenance, restoration, or demolition activities or unplanned events due to vessel deterioration.

Winzler & Kelly performed this Screening Level Hazardous Materials Survey of the Wapama on June 14, 2005. The investigation was conducted by Lionel S. Reynolds, CIH and Manuel F. Luna who are both California Certified Asbestos Consultants and Lead Inspector/Risk Assessors. This work was conducted in accordance with our proposal dated April 11, 2005. We understand this work is being conducted under National Park Service (NPS) Contract C9000031900 for Architect Engineering Services throughout the Pacific West Region.

All findings and conclusions presented in this report are based on a review of our review of the 1986 Historic Structure Report, on-site visual survey, sampling and testing results, and a review of the draft proposed options for the vessel.

METHODOLOGY

General Survey Conditions.

Winzler & Kelly was unable to access confined or highly restricted spaces including barge tanks, bunker oil fuel tanks, boiler/boiler stack and bilges. We also had limited access in certain areas including fo'c'sle compartments and deck, and cabin decks (and above) due to structurally unsound decking and railing. Accessible deck areas of Barge 214 were also included in the survey as any maintenance, restoration or demolition work on the Wapama might be expected to also impact barge coatings.

Asbestos – Survey Methodology

Visual identification was performed by assessing visible and accessible marine architectural and mechanical components for the presence of suspect asbestos-containing materials (ACM). The survey was conducted in a non-destructive manner meaning that exposed materials and finishes were not disturbed to search for potential materials concealed beneath or behind the surface material. Paint, caulking, thermal system insulation and other materials were sampled at locations of existing damaged, loose, or delaminating materials.

The most obvious and significant suspect ACM identified as part of this screening was bulk sampled in using sampling guidelines established by the Environmental Protection Agency (EPA). Bulk sample collection was conducted using the methods described in Appendix K of 8 California Code of Regulations (CCR) Section 1529 asbestos.

The following summarizes the asbestos sampling procedures utilized.

- A sampling scheme was developed based upon the location and extent of the various suspect ACM materials based on visual observation.
- Trained personnel using appropriate sampling tools and leak-tight containers collected bulk samples.
- Bulk sampling tools were decontaminated after the collection of each bulk sample to prevent the spread of secondary contamination to subsequent bulk samples.
- Each bulk sample was labeled with a unique sample identification number and recorded on a Bulk Sample Log.
- A Chain of Custody Record was maintained for bulk samples collected.

Asbestos - Analytical Methodology

Samples of suspect ACM were sent to the Forensic Analytical (Forensic) laboratory in Hayward, California. The Forensic is accredited under the National Voluntary Laboratory Accreditation Program (NVLAP) of the National Institute of Standards & Technology (NIST) and the California Environmental Laboratory Accreditation Program (Cal-ELAP) for asbestos analysis. The samples were submitted for analysis by Polarized Light Microscopy (PLM) utilizing dispersion staining techniques in accordance with the EPA's "Method for the Determination of Asbestos in Bulk Building Materials" U.S. EPA/600/R-93/116, dated July 1993 and adopted by the NVLAP as Test Method Code 18/A01. Using this method, the asbestos content of each discernable material layer is analyzed and reported.

Lead – Survey/Analytical Methodology

This survey included limited testing for lead-based paint (LBP) using a Niton XL300 (serial # U4287NR5566) X-Ray Fluorescence (XRF) direct read instrument and results presented herein are largely representative (but not all inclusive) of typical painted/coated surfaces present this vessel. In addition, two paint chip samples were collected of laboratory analysis of representative coatings that reported low lead levels based on the XRF testing. One of the two paint chip samples analyzed represented the red bottom paint and the other the red barge deck paint. Both samples were sent to laboratory accredited by the American Industrial Hygiene Association (AIHA) under the EPA's Environmental Lead Laboratory Accreditation Program (ELLAP). Any untested painted/coated surfaces should be assumed to be lead-based or lead-containing paint or coating unless paint chip analytical results are below detection levels.

To provide a preliminary evaluation of the presence of lead in coatings, and assist in compliance with 8 CCR 1532.1, 1536, and 1537, the XRF test results and bulk paint chip sample data were interpreted as follows:

- Positive results (lead-containing) were determined when analytical results revealed a lead concentration greater than the laboratory analytical detection limit. Any coating with detectable lead is considered to be a Lead Containing Paint (LCP) subject to Cal/OSHA and Cal/EPA regulation. When the lead content of a LCP exceed the threshold discussed below it is considered to be Lead-Based Paint.

- Negative results were determined when analytical results revealed a lead concentration less than the detection limit of the laboratory analytical procedure. *Note: Negative results based on XRF are not sufficient to conclude that no detectable lead would be present based on the laboratory wet chemistry analysis methods due a much lower sensitivity of the non-destructive method.*

Lead-Containing Paints (LCPs) are coatings that contain any detectable lead as defined by Cal/OSHA. Lead-Based Paint (LBP) is defined as any painted surface exceeding 5,000 ppm or 1.0 mg/cm² or greater as set forth in the Housing and Urban Development (HUD) and Environmental Protection Agency (EPA) regulations for residential and facilities frequented by young children. The same criteria were adopted in the California Department of Health Services regulations (DHS) for public and commercial buildings.

Other Potential Hazardous Materials

Toxic Metals: In addition to lead, the paints are likely to contain other toxic metals that may impact surface preparation, vessel stabilization, restoration, and/or any demolition activities. In order to evaluate this potential, samples of representative coatings were evaluated by composite sampling and analysis. Composite samples of the exterior hull paint (red) below the water line and the exterior topside hull, bulwark and cabin paint (white) were collected and analyzed for the 17 Title 22 metals. These included the following toxic metals: antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, and zinc. The two samples were sent to a California certified laboratory for analysis of the metals by EPA method 3050B/6010B (all metal except mercury) and EPA method 7471A for mercury.

Other Hazardous Materials: No other materials were sampled, however the existing fuel tanks in the Wapama contain residual fuel reported to be bunker C and there appears to be a similar black, oily type material seeping out of the hull on the port side, aft end in the general vicinity of the fuel tanks. The barge is reported to have been used as a fuel tank barge carrying bunker C fuel and is likely to have some residual fuel in its tanks.

No other suspect hazardous materials were noted however there may be some undetected or concealed hazardous materials in ship spaces and/or equipment

RESULTS

Asbestos

Winzler & Kelly collected 21 bulk suspect asbestos samples from the Wapama and one (1) sample from Barge 214. Suspect ACMs sampled during this survey are listed in Section 2 – Suspect Asbestos-Containing Material Sample Results. Laboratory analytical results for suspect ACMs are listed in Section 4 - Laboratory Analytical Reports. Photographs of selected ACM conditions detected are provided in Section 5 - Photographs

Barge 214: No asbestos was detected in the one sample of non-skid deck coating on the Barge.

Wapama:
Asbestos was detected in the following materials on the vessel:

- Pipe insulation in Engine Room (Lower Level)
- Tank insulation in Engine Room (Lower Level)
- Boiler system firebox insulation (various) in Engine Room (Lower Level)
- Sheet gasket material (not installed) in Engine Room Upper Level
- Sheet gasket or heat shield material, under sheet metal on ceiling at aft bulkhead, Upper level Engine Room

The following materials had no detectible asbestos in samples collected on the Wapama:

- Hull caulking, putty and oakum
- Cement fill and plugs sampled
- Hull paint
- Concrete flooring material in Galley
- Tar-like deck sealant between planks
- Refractory Brick & Cement mortar (however associated insulation contained asbestos & therefore the brick/mortar should be considered contaminated)

In addition, the following materials are presumed to contain asbestos: All un-sampled insulation on piping, manifolds, etc in the engine room; white woven gaskets in upper level engine room cabinet; and window glazing compounds.

Lead

Winzler & Kelly performed a total of 61 XRF Lead-Based Paint (LBP) screening tests and two (2) paint chip samples from the Wapama and associated Barge. These included four tests of the barge including the associated steel shoring providing additional support to the Wapama hull and 57 tests of various painted surfaces on the Wapama. The results of the XRF testing and paint chip sampling are tabulated in Section 3 – XRF Lead-Based Paint Test Results. The laboratory reports for the paint chips are provided in Section 4 – Laboratory Analytical Reports. A photograph of the starboard side of the vessel in included in Section 4.0 – Photographs.

The following painted components were found to have a lead level of 1.0 mg/cm² or greater and are therefore considered to be Lead-Based Paint:

- White paint on bulwarks, cabin sheathing, engine room sheathing, Fo'c'sle sheathing (siding) , main deck rail, doors, hand rails, , baluster, window casing, officers quarters wall (interior), engine room bulkhead (interior), and galley door frame. Other similar white painted wood components, including exterior hull should also be considered to be LBP unless exhaustively tested. Also see results of composite paint sample analysis for Title 22 metals.
- Grey paint on bulwarks, engine room sheathing, engine room lower plate and covering board. Other grey painted wood components, including the topside exterior hull, should be considered to be LBP unless exhaustively tested.

- Blue paint on poop deck overhead wood beam.
- Black paint on painted metal components including bitt, winch, boiler stack, stove duct, hand rail and pipe valve support. Painted metal components should be considered LBP unless exhaustively tested.
- Red paint on wood wall, ceiling, and floor in Dining Salon.

Other coatings tested contained lead levels lower than the lead-based paint criteria but should still be considered lead containing coatings or coatings with detectable levels of lead. These include the red hull paint, red barge paint, grey paint on barge shoring supporting the Wapama hull, and the interior green wall/ceiling panel coating. The lead paint chip for the barge deck and the composite sample of red hull paint analyzed for Title 22 metals confirm that there are low but detectable levels of lead in the bottom hull paint of the Wapama and in the red barge deck paint.

Title 22 Metals:

The following is a summary of the analytical results for two composite paint samples analyzed for the 17 Title 22 metals. A copy of the laboratory report is provided in Section 4 – Laboratory Analytical Reports.

- ***Red bottom paint (Wapama)***: The results for the red bottom paint report levels of arsenic at 1,300 milligrams per kilogram (mg/kg), copper at 49,000 mg/kg, and mercury at 67 mg/kg. These results exceed the California Title 22 Total Threshold Limit Concentrations (TTLC) of 1,300 mg/kg for arsenic, 2,500 mg/kg for copper, and 20 mg/kg for mercury respectively. The results also indicate that red bottom paint wastes also need to be tested by the California Waste Extraction Test (WET) and the EPA Toxicity Characteristic Leaching Procedure (TCLP) for lead and zinc (WET only) and possibly cadmium at minimum. All other metals appear to be within regulatory levels for waste disposal.

- ***White top side paint (Wapama)***: The results for the white topside paint report the levels of lead at 64,000 mg/kg which exceeds the TTLC of 1000 mg/kg for lead; and reports the level of zinc at 4,700 mg/kg which nearly exceeds the TTLC of 5,000 mg/kg for zinc. Based on the Title 22 results, the white paint waste would also need to be tested by the California WET test for chromium, mercury, zinc; EPA TCLP test for chromium, and mercury only; and probably cadmium for both tests. All other metals appear to be within regulatory levels for disposal.

Other Suspect Materials

Winzler & Kelly has visually identified Bunker C fuel oil residue in bottom of fuel tanks and as the suspected petroleum hydrocarbon based substance observed to be seeping from the Wapama hull on to a localized area of the Barge deck. It is also anticipated based on reports by others that a limited amount of Bunker C fuel oil (or other petroleum hydrocarbon residue) is likely present in the Barge tanks.

CONCLUSIONS AND RECOMMENDATIONS

Asbestos

Asbestos was confirmed to be present in the engine room on piping, tanks, the boiler system (fire box), heat shield, and gasket materials in the engine room. The thermal system insulation and was in poor conditions and there was evidence of debris below areas of damage. Prior to restoration, stabilization or demolition activities that are like to disturb identified and presumed asbestos containing materials, all impacted known and presumed ACM must be removed by a California registered asbestos contractor. Because of the poor condition of most of the thermal system insulation on piping and mechanical systems and the advance state of the firebox deterioration with spillage of refractory brick mixed with associated asbestos insulation materials, we recommend that all such thermal system insulation and debris be removed and that the engine room be decontaminated regardless of what option selected by the National Park Service for continued storage, restoration or demolition of the vessel.

Pending the asbestos removal and clean-up, the engine room should be restricted to personnel with need to enter only. Further, personnel that need to enter should have, at minimum, hazard communication training for the existing asbestos conditions and be provide any necessary protective equipment required depending on the likelihood of disturbance of the thermal insulation material or debris.

We recommend that all required abatement operations be conducted and overseen by a Certified Asbestos Consultant (CAC) according to a work scope and abatement plans and specification. The selected Contractor should perform all work in compliance with project specifications prepared by a CAC and the most recent edition of all applicable Federal, State, and local regulations, standards, and codes governing abatement, transport, and disposal of asbestos-containing materials.

Lead

All renovation involving potential and identified LBP/LCP surfaces should be conducted in accordance with Title 8, California Code of Regulations (CCR), Section 1532.1 and Title 17, CCR, Division 1, Chapter 8

If the lead content of the LCP is 600 parts per million or greater, an initial exposure assessment is required by Cal/OSHA for any work disturbing the paint. . For certain higher risks tasks listed in 8 CCR 1532.1, an initial assessment is required regardless of lead level as long is lead is detected. For these tasks, often referred to as "trigger tasks", additional minimum worker protection measures including lead hazard communication training, appropriately selected respiratory protection, protective clothing & equipment, biological monitoring, change areas and hand washing facilities are required during the initial exposure assessment. These "trigger" tasks include, but are not limited to: manual demolition, paint scraping, sanding, heat gun applications, power tool cleaning; lead burning, abrasive blasting (and associated clean up), welding, cutting, and torching operations where lead or LCC is present. Certain work practices apply regardless of exposure levels such as use of wet methods and/or HEPA filtered vacuums when feasible.

Depending on exposure assessment results, additional worker protective requirements may apply.

At present there are no applicable local, state or federal laws requiring mandatory abatement of lead or lead coatings following the identification of lead-containing materials and coatings. However, the disturbance of the identified lead containing materials requires compliance with worker protection rules including agency notification prior to start up. Cal OSHA requires notification prior to disturbing more than 100 square feet of LBP and DHS requires notification of any hazard abatement activity involving any quantity of LBP. Work associated with LBP hazard reduction or involving personnel exposures over the Cal/OSHA permissible exposure limit (PEL) should be completed by DHS Certified Lead Workers. In addition, based on the results of this survey, most of the paint coatings tested have lead content that exceeds limits that require special storage, transport and disposal as hazardous waste. The loose, peeling paint on the Wapama also poses a significant risk of environmental release due to the immediate proximity of surface waters of the bay. This risk is further exacerbated by the possible catastrophic structural failure or collapse of the vessel.

Removal of loose lead containing paint and/or components (e.g. planking) will require containment to prevent release during removal operations. Any lead-related construction including surface preparation, component removal or demolition should be conducted according to construction documents properly prepared by a certified lead project designer and overseen by a certified lead inspector, risk assessor or monitor.

Contractor personnel should perform all lead-related remediation, stabilization, or demotion work in compliance project specifications prepared by a certified lead project designer and in conformance with the most recent edition of all applicable Federal, State, and local regulations, standards, and codes governing abatement, transport, and disposal of lead containing/contaminated materials.

Title 22 Metals:

Winzler & Kelly's limited composite sampling of loose paints found that representative paint coatings contained toxic metals above California hazardous waste TTLC criteria for various metals depending on type of paint. Toxic metals likely involved at hazardous concentrations based on this study include arsenic, copper, lead, mercury, zinc and possibly cadmium and chromium. These findings indicate the additional environmental risks to be mitigated in association with any work that disturbs existing painted surfaces. This includes surface preparation for stabilization/painting of existing coatings and/or construction activities associated with the restoration or demolition vessel in part or whole. The toxic metals detected in the typical Wapama paints tested present an added environmental release risk to that noted above for lead. Needless to say, both environmental and worker protection controls will be required for any work to undertaken prepare the vessel for safe storage, restoration, or demolition. However, the same protective measures and controls required for the lead paint should also be sufficient for these other toxic metals present during paint disturbing activities.

Other Materials:

The small amount of fuel oil seepage noted should be cleaned up as soon as possible. Remaining fuel oil in the fuel oil tanks and bilges will need to be cleaned up prior to moving, restoring or demolishing the vessel. Special care is required to ensure release to surface waters does not occur during continued storage maintenance, stabilization, restoration or demolition of the vessel. Fuel oil residue and contaminated cleaning materials require proper testing and disposal and/or recycling.

Should materials similar to those identified in this report or, other forms of suspect hazardous materials be identified, maintenance personnel/contractors should be instructed to cease work any activities that may initiate an exposure episode, and notify the appropriate NPS National Historic Landmark personnel so that the suspect condition can be investigated.

Other Safety Factors

Physical safety was not within Winzler & Kelly's survey scope and no attempt was made to conduct a general safety survey beyond that necessary to conduct our team's work on the vessel. However, we would be remiss if we did not point out that the continual degradation of the structural integrity of the vessel appears to present a significant safety risk to NPS personnel and any authorized or unauthorized visitors. Deterioration of the various deck areas and rails creates hazards that make unrestricted access inadvisable. In addition, there appears to be an increasing danger of falling objects that could seriously injure persons working or standing below on the barge deck. The barge deck, while posted, is currently physically accessible to anyone who cares to trespass. In our opinion, the overall the combination of physical and environmental hazards associated with the vessel's continual deterioration requires a rapid, high priority response to mitigate the hazard and associated liability. Regardless of what option the NPS selects for the Wapama's future use (or disposal) these conditions need priority consideration.

If you have any questions or concerns regarding this document please do not hesitate to call us at (510) 667-6440.

Respectfully Submitted,

Winzler & Kelly Consulting Engineers

Reviewed & Approved By

Lionel S. (Butch) Reynolds, CIH
Senior Project Manager
CAC # 92-439
DHS # 225

Charles R. Bove
Director of Industrial Hygiene
CAC. # 92-0160

SECTION 2

SUSPECT ASBESTOS-CONTAINING MATERIAL SAMPLE RESULTS

SUSPECT ASBESTOS CONTAINING MATERIAL SAMPLE RESULTS

Project Name: S.S. Wapama NHL Steam Schooner Survey & Evaluation
Project Number: 103025001-35-187

Sample #	Material Type	Material Description (by layer)	Sample Location	Material Location	Sample Result (% Asbestos) *
A-1	Caulking	Grey putty Red Paint	Rudder at Gudgeon Red	Hull, where occurs	ND ND
A-2	Cement Fill	Grey cement Red Paint	Rudder Post	Hull, where occurs	ND ND
A-3	Caulking, Oakum	Grey Non-fibrous matl. Red Paint Brown fibrous matl.	Hull, Stbd. Side between strakes	Hull Seams, where occurs	ND ND ND
A-4	Putty	Grey Putty Red Paint	Stbd. Hull at garboard strake, near keel	Hull, where occurs	ND ND
A-5	Cement Plug	Grey cement Red Paint	Stbd. Hull Fastener Plug	Hull, where occurs	ND ND
A-6	Caulking, Oakum	Grey non-fibrous matl. Red Paint Brown fibrous matl.	Stbd. Hull Seam between strakes	Hull, where occurs	ND ND ND
A-7	Putty	Grey putty Red paint	Stbd. Hull	Hull, where occurs	ND ND
A-8	Caulking	Grey putty Red Paint	Port Hull at Seam	Hull, where occurs	ND ND
A-9	Non-Skid Coating	Grey material Paint	Barge deck, port side	Barge deck, where occurs	ND ND
A-10	Putty	White putty Paint	Main Deck at base of Engine Room House	Where occurs	ND ND

* ND – None Detected; ** % asbestos = percent chrysotile (chry.) asbestos unless otherwise noted; Amos.= Amosite asbestos

SUSPECT ASBESTOS CONTAINING MATERIAL SAMPLE RESULTS

Project Name: S. S. Wapama NHL Steam Schooner Survey & Evaluation
Project Number: 103025001-35-187

Sample #	Material Type	Material Description (by layer)	Sample Location	Material Location	Sample Result (% Asbestos) *
A-11	Concrete deck	Grey cement Paint	Galley floor	Galley over wood deck	ND
A-12	Sealant	Black tar	Poop deck, port side	Deck plank seams, where occur	ND
A-13	Thermal System Insulation (TSI)	Preformed TSI, beige/tan	Engine Room, Lower Level, Stbd Side above Generators	Engine Room piping, where occurs	25%
A-14	TSI	Preformed TSI, beige	Engine Room, Lower Level, Port Side, above Pumps	Engine Room piping, where occurs	35% chry + 7% Amos.
A-15	TSI	Tank TSI, beige	Engine Room, Port Side, hot water tank	Engine Room, Hot Water Tank	20% Chry. + & 7% Amos.
A-16	Refractory Brick	Refractory Brick, pink/tan	Engine Room, Lower Level, Boiler Firebox	Refractory Debris at base of Stbd Boiler fire box	ND
A-17	TSI	Boiler firebox insulation, white/grey	Engine Room, Lower Level, Boiler Firebox	With refractory Debris at base of Stbd Boiler fire box	35%
A-18	TSI	Boiler firebox insulation, grey fluffy matl	Engine Room, Lower Level, Boiler Firebox	With refractory Debris at base of Stbd Boiler fire box	60%
A-19	Mortar	Mortar, pink/tan cement	Engine Room, Lower Level, Boiler Firebox	With refractory Debris at base of Stbd Boiler fire box	ND
A-20	TSI	Fluffy, fibrous, red	Engine Room, Lower Level, Boiler Firebox	With refractory Debris at base of Stbd Boiler fire box	50%

* ND – None Detected; ** % asbestos = percent chrysotile (chry.) asbestos unless otherwise noted; Amos.= Amosite asbestos

SUSPECT ASBESTOS CONTAINING MATERIAL SAMPLE RESULTS

Project Name: S.S. Wapama NHL Steam Schooner Survey & Evaluation
Project Number: 103025001-35-187

Sample #	Material Type	Material Description (by layer)	Sample Location	Material Location	Sample Result * (% Asbestos) **
A-21	Gasket Sheet	Ankrorite Sheet, white	Engine Room, Upper Level, fwd of Steam Chest	Sample location only	90%
A-22	TSI sheet	TSI heat shield sheet, grey	Engine Room, Upper Lever, under sheet metal heat shield above stove duct at bulkhead.	Sample location only	90%

* ND – None Detected; ** % asbestos = percent chrysotile (chry.) asbestos unless otherwise noted; Amos.= Amosite asbestos

SECTION 3

XRF LEAD-BASED PAINT TEST RESULTS

XRF Lead-Based Paint Test Results
SS Wapama - Steam Schooner

Location	Side/Sample Location	Substrate	Feature	Color	Condition	XRF Result (mg/cm2)	Flame AA Sample Number	Flame AA Result (wt%))
Hull	Port, Exterior	Wood	Plank	Red	Poor	0.01	P-2	<0.006
Hull	Port, Exterior	Wood	Keel	Red	Poor	0.01	NA	NA
Barge	Port, Exterior	Metal	Deck	Red	Poor	0	P-1	0.011
Rudder	Port, Exterior	Metal	gudgeon	Red	Poor	0	NA	NA
Rudder	Port, Exterior	Metal	pindle	Red	Poor	0.02	NA	NA
Hull	Stbd. Exterior	Wood	Plank	Red	Poor	0.04	NA	NA
Barge	Port, Exterior	Metal	Deck	Red	Poor	0.02	NA	NA
Barge	Port, Exterior	Metal	Shoring	Gray	Poor	0.02	NA	NA
Barge	Port, Exterior	Metal	Shoring	Gray	Intact	0.02	NA	NA
Main Deck	**Port, Exterior**	**Wood**	**Bulwark**	**White**	**Fair**	**4.79**	**NA**	**NA**
Main Deck	Port, Exterior	Wood	Cap Rail	White	Fair	0.09	NA	NA
Main Deck	**Port, Exterior**	**Wood**	**Bulwark**	**Gray**	**Poor**	**4.63**	**NA**	**NA**
Main Deck	**Port, Exterior**	**Wood**	**Bulwark**	**Gray**	**Poor**	**1.3**	**NA**	**NA**
Main Deck	**Port, Exterior Engine Room House**	**Wood**	**Sheathing**	**Gray**	**Poor**	**16**	**NA**	**NA**
Main Deck	Port, Exerior Engine Room House	Wood	Lower Plate	Gray	Poor	0.48	NA	NA
Main Deck	Port, Exterior Engine Room House	Wood	Deck level, Covering Board	Gray	Poor	0.4	NA	NA
Main Deck	**Port, Exterior Engine Room House**	**Wood**	**Sheathing**	**White**	**Poor**	**5.1**	**NA**	**NA**
Main Deck	Port, Exterior, Fo'c'sle	Wood	Door	White	Fair	0.12	NA	NA
Main Deck	**Port, Exterior, Fo'c'sle**	**Wood**	**Sheathing**	**White**	**Fair**	**7.6**	**NA**	**NA**

XRF Lead-Based Paint Test Results
SS Wapama - Steam Schooner

Location	Side/Sample Location	Substrate	Feature	Color	Condition	XRF Result (mg/cm2)	Flame AA Sample Number	Flame AA Result (wt%))
Main Deck	Port, Exterior	Wood	Main Rail	White	Poor	2.1	NA	NA
Main Deck	Stbd. Exterior	Wood	Cap Rail	White	Poor	0.12	NA	NA
Main Deck	Stbd. Exterior	Wood	Bulwark	Gray	Poor	5.1	NA	NA
Main Deck	Stbd. Exterior	Wood	Bulwark	White	Poor	7.3	NA	NA
Main Deck	Stbd. Exterior	Wood	Waterway	White	Poor	6.8	NA	NA
Main Deck	Engine Room House, Stbd. Exterior	Wood	Door	White	Poor	2.7	NA	NA
Main Deck	Stbd. Exterior	Wood	Siding	White	Poor	5.7	NA	NA
Poop Deck	Stbd. Exterior	Wood	Siding	White	Poor	6.6	NA	NA
Poop Deck	Stbd. Exterior	Wood	Beam	Blue	Poor	3.1	NA	NA
Poop Deck	Stbd. Exterior	Metal	Bitt	Black	Poor	5.1	NA	NA
Poop Deck	Stbd. Exterior	Wood	Hand Rail	White	Poor	3.7	NA	NA
Poop Deck	Stbd. Exterior	Wood	Baluster	White	Poor	7.6	NA	NA
Poop Deck	Stbd. Exterior	Wood	Wall	Black	Intact	16	NA	NA
Cabin Deck	Starbord, Exterior	Wood	Door	White	Intact	2.4	NA	NA
Cabin Deck	center, aft.	Metal	Winch	Black	Poor	1.8	NA	NA
Cabin Deck	Port, cabin	Wood	Sheathing	White	Poor	5.7	NA	NA

XRF Lead-Based Paint Test Results
SS Wapama - Steam Schooner

Location	Side/Sample Location	Substrate	Feature	Color	Condition	XRF Result (mg/cm2)	Flame AA Sample Number	Flame AA Result (wt%))
Cabin Deck	Port	Wood	Window Casing	White	Intact	3.4	NA	NA
Cabin Deck	Port, Cabin	Wood	Bunk Bed	Varnish	Intact	0	NA	NA
Cabin Deck	Port	Metal	Winch AFT	Black	Intact	0.07	NA	NA
Boat Deck	Wheel House	Metal	Boiler Stack	Grey	Intact	5.1	NA	NA
Boat Deck	Wheel House	Wood	Sheathing	Green	Intact	0.34	NA	NA
Boat Deck	Wheel House	Wood	E	Green	Intact	0.6	NA	NA
Boat Deck	Officer's Quarters	Wood	Bunk/Bed	Varnish	Intact	0.01	NA	NA
Boat Deck	Officer's Quarters	Wood	Door	Varnish	Intact	0	NA	NA
Boat Deck	Officers Bathroom	Wood	Wall	White	Intact	13	NA	NA
Boat Deck	Officers Quarters	Wood	Ceiling	Green	Intact	0.11	NA	NA
Boat Deck	Officers Quarters	Wood	Ceiling	Green	Fair	0.23	NA	NA
Engine Room	Engine Steam Chest	Metal	Piston Head Cover	Black	Fair	0.7	NA	NA
Engine Room	Bulk Head	Metal	AFT Bulk Head	White	Intact	13	NA	NA
Engine Room	Overhead	Metal	Stove Duct	Black	Intact	13	NA	NA
Engine Room	Engine Support	Wood	Support	White	Intact	3.8	NA	NA
Engine Room	Hand Rail	Metal	Handrail	Black	Intact	3.4	NA	NA

XRF Lead-Based Paint Test Results
SS Wapama - Steam Schooner

Location	Side/Sample Location	Substrate	Feature	Color	Condition	XRF Result (mg/cm2)	Flame AA Sample Number	Flame AA Result (wt%))
Engine Room	Valve	Metal	Valve Support	Yellow	Intact	0.75	NA	NA
Engine Room	Valve	Metal	Valve Support	Black	Intact	3.5	NA	NA
Engine Room	Bulk Head	Wood	Bulkhead	White	Fair	3	NA	NA
Dining Salon	Table	Wood	Table Top	Red	Fair	0.21	NA	NA
Galley	Stbd Side	Wood	Hand Rail	Red	Fair	0.08	NA	NA
Dining Salon	Stbd. Side	Wood	Deck	Red	Fair	0.09	NA	NA
Dining Salon	Stbd. Side	Wood	Wall	Red	Fair	1.17	NA	NA
Dining Salon	Stbd Side	Wood	Ceiling	Red	Fair	1.14	NA	NA
Galley	Main Deck	Wood	Floor	Red	Fair	1.33	NA	NA
Galley	Main Deck	Wood	Door Frame	White	Fair	1.12	NA	NA

NA = Not Applicable PPM = Parts Per Million mg/cm² = milligrams/centimeters square

SECTION 4

LABORATORY ANALYTICAL REPORTS

Bulk Asbestos Analysis

(EPA Method 600/R-93-116, Visual Area Estimation)

Winzler & Kelly
Project Manager
2[illegible]34 Teagarden St.

San Leandro, CA 94577

Client ID: 2735
Report Number: B074241
Date Received: 06/21/05
Date Analyzed: 06/23/05
Date Printed: 06/23/05
First Reported: 06/23/05

Job ID/Site: 1030205001 - Steam Schooner "Wapama`

Date(s) Collected: 06/20/2005

FASI Job ID: 2735-128
Total Samples Submitted: 22
Total Samples Analyzed: 22

Sample ID	Lab Number	Asbestos Type	Percent in Layer	Asbestos Type	Percent in Layer	Asbestos Type	Percent in Layer
A-1	10425301						
Layer: Grey Putty			ND				
Layer: Paint			ND				
Total Composite Values of Fibrous Components:		**Asbestos (ND)**					
Cellulose (Trace)							
A-2	10425302						
Layer: Grey Cementitious Material			ND				
Layer: Paint			ND				
Total Composite Values of Fibrous Components:		**Asbestos (ND)**					
Cellulose (Trace)							
A-3	10425303						
Layer: Grey Non-Fibrous Material			ND				
Layer: Paint			ND				
Layer: Brown Fibrous Material			ND				
Total Composite Values of Fibrous Components:		**Asbestos (ND)**					
Cellulose (10 %)							
A-4	10425304						
Layer: Grey Putty			ND				
Layer: Paint			ND				
Total Composite Values of Fibrous Components:		**Asbestos (ND)**					
Cellulose (Trace)							
A-5	10425305						
Layer: Grey Cementitious Material			ND				
Layer: Paint			ND				
Total Composite Values of Fibrous Components:		**Asbestos (ND)**					
Cellulose (Trace)							
[illegible]	10425306						
Layer: Grey Non-Fibrous Material			ND				
Layer: Paint			ND				
Layer: Brown Fibrous Material			ND				
Total Composite Values of Fibrous Components:		**Asbestos (ND)**					
Cellulose (10 %)							

[redacted] Forensic Analytical [redacted]

Client Name: Winzler & Kelly

Report Number: B074241
Date Printed: 06/23/05

S[redacted]ple ID	Lab Number	Asbestos Type	Percent in Layer	Asbestos Type	Percent in Layer	Asbestos Type	Percent in Layer
A-7	10425307						
[redacted]ayer: Grey Putty			ND				
ayer: Paint			ND				
Total Composite Values of Fibrous Components:		Asbestos (ND)					
[redacted]ellulose (Trace)							
A-8	10425308						
Layer: Grey Putty			ND				
[redacted]ayer: Paint			ND				
Total Composite Values of Fibrous Components:		Asbestos (ND)					
Cellulose (Trace)							
A[redacted]	10425309						
Layer: Grey Non-Fibrous Material			ND				
Layer: Paint			ND				
[redacted]otal Composite Values of Fibrous Components:		Asbestos (ND)					
Cellulose (Trace)							
A[redacted]0	10425310						
[redacted]ayer: White Putty			ND				
Layer: Paint			ND				
[redacted]otal Composite Values of Fibrous Components:		Asbestos (ND)					
ellulose (Trace)							
A-11	10425311						
[redacted]ayer: Grey Cementitious Material			ND				
ayer: Paint			ND				
Total Composite Values of Fibrous Components:		Asbestos (ND)					
[redacted]ellulose (Trace)							
A-12	10425312						
Layer: Black Tar			ND				
[redacted]otal Composite Values of Fibrous Components:		Asbestos (ND)					
Cellulose (Trace)							
A-13	10425313						
[redacted]ayer: Tan Semi-Fibrous Material		Chrysotile	25 %				
Total Composite Values of Fibrous Components:		Asbestos (25%)					
Cellulose (Trace)							
A[redacted]4	10425314						
Layer: Off-White Semi-Fibrous Material		Chrysotile	35 %	Amosite	7 %		
Layer: Beige Woven Material			ND				
[redacted]otal Composite Values of Fibrous Components:		Asbestos (38%)					
Cellulose (10 %)							
A-15	10425315						
[redacted]ayer: Off-White Semi-Fibrous Material		Chrysotile	20 %	Amosite	7 %		
Total Composite Values of Fibrous Components:		Asbestos (27%)					
[redacted]ellulose (Trace)							

[redacted]

Forensic Analytical

Report Number: B074241
Client Name: Winzler & Kelly
Date Printed: 06/23/05

S[redacted]ple ID	Lab Number	Asbestos Type	Percent in Layer	Asbestos Type	Percent in Layer	Asbestos Type	Percent in Layer
A-16	10425316						
[redacted]ayer: Tan Cementitious Material			ND				
Total Composite Values of Fibrous Components:		Asbestos (ND)					
Cellulose (Trace)							
A[redacted]7	10425317						
Layer: Off-White Semi-Fibrous Material		Chrysotile	35 %				
[redacted]otal Composite Values of Fibrous Components:		Asbestos (35%)					
ellulose (Trace)							
A-18	10425318						
[redacted]ayer: Beige Semi-Fibrous Material		Chrysotile	60 %				
otal Composite Values of Fibrous Components:		Asbestos (60%)					
Cellulose (10 %)							
A[redacted]	10425319						
ayer: Tan Cementitious Material	-		ND				
Total Composite Values of Fibrous Components:		Asbestos (ND)					
[redacted]ellulose (Trace)							
A-20	10425320						
Layer: Red-Brown Semi-Fibrous Material		Chrysotile	50 %				
[redacted]otal Composite Values of Fibrous Components:		Asbestos (50%)					
Cellulose (10 %)							
A-21	10425321						
[redacted]ayer: Light Grey Fibrous Material		Chrysotile	90 %				
Total Composite Values of Fibrous Components:		Asbestos (90%)					
[redacted]ellulose (2 %)							
A-2	10425322						
Layer: Light Grey Fibrous Material		Chrysotile	90 %				
[redacted]otal Composite Values of Fibrous Components:		Asbestos (90%)					
ellulose (2 %)							

Jim Flores

James Flores, Laboratory Supervisor, Hayward Laboratory

Note: Limit of Quantification ('LOQ') = 1%. 'Trace' denotes the presence of asbestos below the LOQ. 'ND' = 'None Detected'.

nalytical results and reports are generated by Forensic Analytical at the request of and for the exclusive use of the person or entity (client) named on such report. Results, ports or copies of same will not be released by Forensic Analytical to any third party without prior written request from client. This report applies only to the sample(s) sted. Supporting laboratory documentation is available upon request. This report must not be reproduced except in full, unless approved by Forensic Analytical. The client is ol[redacted] responsible for the use and interpretation of test results and reports requested from Forensic Analytical. This report must not be used by the client to claim product n sement by NVLAP or any other agency of the U.S. Government. Forensic Analytical is not able to assess the degree of hazard resulting from materials analyzed. orensic Analytical reserves the right to dispose of all samples after a period of thirty (30) days, according to all state and federal guidelines, unless otherwise specified. All mples were received in acceptable condition unless otherwise noted.

Forensic Analytical # 2735 | 2/8 | **Analysis Request Form**

Client Name & Address: Winzler & Kelly 2984 Teagarden St. San Leandro, CA 94577	P.O. #: 103020500/ Date: 6 / 21 / 05 Turn Around Time: 48 hr/ 12hr / 24hr / [✓ 48 hr] / ext: ______ Due Date: 6 / 23 / 05 Due Time: ___ : ___ am [✓ pm] ☒ PLM: ☒ Standard / ☐ Point Count ☐ PCM: NIOSH 7400
Contact: Butch Reynolds	☐ TEM Air: ☐ AHERA / ☐ Yamate2 / ☐ NIOSH 7402
Phone #: (510) 667-6440	☐ TEM Bulk: ☐ Quantitative / ☐ Qualitative / ☐ Chatfield ☐ TEM Water: ☐ Potable / ☐ Non-Potable / ☐ Wt % ☐ TEM Microvac
Fax#: (510) 667-6444	☐ Special Project:
Site: Steam Schooner "WAPAMA"	☐ Metals Analysis: Method ______
Job:	Matrix: ______ Analytes: ______

Comments:

Sample ID	Date/ Time	Sample Location/Description	FOR AIR SAMPLES ONLY				Sample Area or Air Volume
			Type	Time On/Off	Avg. LPM	Total Time	
A-1	[illegible]	Calking - Tan & white Rudder Hinged Plate	A P C				
A-2	Starboard Side	Cement like, at Rudder Support, Below Screw	A P C				
A-3		Calking Fiber (Oaking) Between Strakes	A P C				
A-4		Gray Putty (w Red Paint) At Garboard (near keel)	A P C				
A-5		Plug over Knot Hole (Fastner Plug)	A P C				
A-6		Fiber Calking (Oaking) Seam Between Strakes	A P C				
A-7		Gray Putty (w Red Paint)	A P C				
A-8	Port Side	Gray Calking, Red Paint and Fiber (Oaking)	A P C				
A-9		Barge Metal Deck - (Non-Skid Surface)	A P C				
A-10		White Putty - Bottom of Engine Rm House (Main Deck	A P C				

Sampled by: C. S. Reynolds Date: 6/14/05 Time: ___ : ___

Shipped via: ☐ Fed Ex ☐ Airborne ☐ UPS ☐ US Mail ☐ Courier ☐ Drop Off ☐ Other:

Relinquished by: Date / Time: 6-21-05	Relinquished by: Date / Time:	Relinquished by: Date / Time:
Received by: Date / Time: 06/21/05 1PM Condition Acceptable? ☑ Yes ☐ No	Received by: Date / Time: Condition Acceptable? ☐ Yes ☐ No	Received by: Date / Time: Condition Acceptable? ☐ Yes ☐ No

Forensic Analytical # 2735

Analysis Request Form

Client Name & Address: Winzler & Kelly 2984 Teagarden St. San Leandro, CA. 94577	P.O.#: 103020500 / Date: 6 / 21 / 05 Turn Around Time: 48 hr/ 12hr / 24hr / [✓ 48 hr] / ext: ____ Due Date: 6 / 23 / 05 Due Time: ____ am/[✓ pm] ☒ PLM: ☐ Standard / ☐ Point Count ☐ PCM: NIOSH 7400
Contact: Butch Reynolds Phone #: (510) 667- 6440 Fax#: (510) 667- 6444	☐ TEM Air: ☐ AHERA / ☐ Yamate2 / ☐ NIOSH 7402 ☐ TEM Bulk: ☐ Quantitative / ☐ Qualitative / ☐ Chatfield ☐ TEM Water: ☐ Potable / ☐ Non-Potable / ☐ Wt % ☐ TEM Microvac ☐ Special Project:
Site: Steam Schooner "Wapama" Job:	☐ Metals Analysis: Method ____ Matrix: ____ Analytes: ____

Comments:

Sample ID	Date/ Time	Sample Location/Description	FOR AIR SAMPLES ONLY				Sample Area or Air Volume
			Type	Time On/Off	Avg. LPM	Total Time	
A-11	Port side	Concrete Finish over wood Deck - (Galley)	A P C				
A-12		Black tar between Boat Deck deck planks.	A P C				
A-13	Port side Engine room	Pipe insulation (TSI) pipe on top of Generator	A P C				
A-14		Pipe Insulation (TSI) Pipes above Pumps	A P C				
A-15		Insulation over Tank (Port Side)	A P C				
A-16		Boiler Refratory Brick (inside Fire Box) (Pink)	A P C				
A-17		Boiler Firebox. white & Gray Insulation	A P C				
A-18		Boiler Fire Box - "Fluffy" insulation (Gray)	A P C				
A-19		Fire Box mortar (Pink)	A P C				
A-20		Fire Box insulation (Red)	A P C				

Sampled by: C. S. Reynolds Date: 6/ 14 / 05 Time: ___ : ___

Shipped via: ☐ Fed Ex ☐ Airborne ☐ UPS ☐ US Mail ☐ Courier ☐ Drop Off ☐ Other:

Relinquished by: Date / Time: 6-21-05	Relinquished by: Date / Time:	Relinquished by: Date / Time:
Received by: Date / Time: 06/21/05 1PM Condition Acceptable? ☑ Yes ☐ No	Received by: Date / Time: Condition Acceptable? ☐ Yes ☐ No	Received by: Date / Time: Condition Acceptable? ☐ Yes ☐ No

Forensic Analytical #2735

Analysis Request Form

Client Name & Address:
WINZLE & KELLY
2981 TEAGARDEN ST.
SAN LEANDRO, CA. 94577

P.O. #: 1030205001 Date: 6 / 21 / 05

Turn Around Time: 48 hr/ 12hr / 24hr / [✓ 48 hr] / ext: ____

Due Date: 6 / 23 / 05 Due Time: ___ : ___ am/[✓ pm]

☒ PLM: ☐ Standard / ☐ Point Count ☐ PCM: NIOSH 7400

☐ TEM Air: ☐ AHERA / ☐ Yamate2 / ☐ NIOSH 7402
☐ TEM Bulk: ☐ Quantitative / ☐ Qualitative / ☐ Chatfield
☐ TEM Water: ☐ Potable / ☐ Non-Potable / ☐ Wt %
☐ TEM Microvac

☐ Special Project:

☐ Metals Analysis: Method ____
Matrix: ____
Analytes: ____

Contact: BUTCH REYNOLDS

Phone #: (510) 667- 6440

Fax#: (510) 667- 6444

Site: STEAM SCHOONER "WAPAMA"

Job:

Comments:

Sample ID	Date/ Time	Sample Location/Description	FOR AIR SAMPLES ONLY				Sample Area or Air Volume
			Type	Time On/Off	Avg. LPM	Total Time	
A-21		ENGINE ROOM UPPER LEVEL "ANKRORITE" MATERIAL	A P C				
A-22		UPPER LEVEL, TOP OF [illegible] ENGINE HEAD - UNDER SHEET METAL HEAT SHIELD	A P C				
			A P C				
			A P C				
			A P C				
			A P C				
			A P C				
			A P C				
			A P C				
			A P C				

Sampled by: L. S. Reynolds Date: 6/14/05 Time: ___ : ___

Shipped via: ☐ Fed Ex ☐ Airborne ☐ UPS ☐ US Mail ☐ Courier ☐ Drop Off ☐ Other:

Relinquished by:	Relinquished by:	Relinquished by:
Date / Time: 6-21-05	Date / Time:	Date / Time:
Received by:	Received by:	Received by:
Date / Time: 06/21/05 1PM	Date / Time:	Date / Time:
Condition Acceptable? ☑ Yes ☐ No	Condition Acceptable? ☐ Yes ☐ No	Condition Acceptable? ☐ Yes ☐ No

Metals Analysis of Paints

Winzler & Kelly
Butch Reynolds
2[illegible]84 Teagarden St.

San Leandro, CA 94577

Client ID:	2735
Report Number:	M071392
Date Received:	06/21/05
Date Analyzed:	06/22/05
Date Printed:	06/22/05
First Reported:	06/22/05

Job ID / Site: 1030205001 - Steam Schooner `Wapama`

FASI Job ID: 2735-128

Sample Number	Lab Number	Analyte	Result	Result Units	Reporting Limit	Method Reference
P[illegible]	30230361	Pb	0.011	wt%	0.007	EPA 3050B/7420
P2	30230362	Pb	< 0.006	wt%	0.006	EPA 3050B/7420

Dave Sandusky, Laboratory Supervisor, Hayward Laboratory

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Forensic Analytical #2735 128

Analysis Request Form

Client Name & Address:
Amelen & Kelly
2984 Teagarden St
San Leandro, CA 94577

Contact: Burl Reynolds

Phone #: (510) 667-6440

Fax#: (510) 667-6444

Site: Steam Schooner "Wapama"

Job:

P.O. #:

Date: 6/21/05

Turn Around Time: 48 hr/ 12hr / 24hr / [✓ 48 hr] / ext:

Due Date: 6/23/05 Due Time: : am/[✓ pm]

☐ PLM: ☐ Standard / ☐ Point Count ☐ PCM: NIOSH 7400

☐ TEM Air: ☐ AHERA / ☐ Yamate2 / ☐ NIOSH 7402
☐ TEM Bulk: ☐ Quantitative / ☐ Qualitative / ☐ Chatfield
☐ TEM Water: ☐ Potable / ☐ Non-Potable / ☐ Wt %
☐ TEM Microvac

☐ Special Project:

☒ Metals Analysis: Method

Matrix: Paint chip

Analytes: AA-Flame - Lead

Comments: Paint Chips - lead

Sample ID	Date/Time	Sample Location/Description	FOR AIR SAMPLES ONLY				Sample Area or Air Volume
			Type	Time On/Off	Avg. LPM	Total Time	
P-1		Paint on Barge metal Deck (Red	A P C				
P-2		Paint on Bottom of Hull (Red)	A P C				
			A P C				
			A P C				
			A P C				
			A P C				
			A P C				
			A P C				
			A P C				
			A P C				

mpled by: L. S. Reynolds Date: 6/14/05 Time: :

oped via: ☐ Fed Ex ☐ Airborne ☐ UPS ☐ US Mail ☐ Courier ☐ Drop Off ☐ Other:

quished by: Time:	Relinquished by: Date / Time:	Relinquished by: Date / Time:
d by: ne: 6/21/05 1Pm Acceptable? ☑ Yes ☐ No	Received by: Date / Time: Condition Acceptable? ☐ Yes ☐ No	Received by: Date / Time: Condition Acceptable? ☐ Yes ☐ No

Forensic Analytical

Final Report

Metals Analysis of Bulks

Winzler & Kelly
Butch Reynolds
2[illegible]84 Teagarden St.

San Leandro, CA 94577

Client ID: 2735
Report Number: M071393
Date Received: 06/21/05
Date Analyzed: 06/28/05
Date Printed: 06/29/05
First Reported: 06/29/05

Job ID / Site: 1030205001 - Steam Schooner `Wapama`

FASI Job ID: 2735-128

Sample Number	Lab Number	Analyte	Result	Result Units	Reporting Limit	Method Reference
I[illegible]2-1	30230363	Ag	2.0	mg/kg	0.5	EPA 3050B/6010B
		As	1300	mg/kg	3	EPA 3050B/6010B
		Ba	530	mg/kg	10	EPA 3050B/6010B
		Be	0.6	mg/kg	0.5	EPA 3050B/6010B
		Cd	6	mg/kg	1	EPA 3050B/6010B
		Co	8	mg/kg	1	EPA 3050B/6010B
		Cr	51	mg/kg	2	EPA 3050B/6010B
		Cu	49000	mg/kg	200	EPA 3050B/6010B
		Hg	67	mg/kg	5	EPA 7471A
		Mo	3	mg/kg	3	EPA 3050B/6010B
		Ni	32	mg/kg	3	EPA 3050B/6010B
		Pb	120	mg/kg	2	EPA 3050B/6010B
		Sb	< 3	mg/kg	3	EPA 3050B/6010B
		Se	< 5	mg/kg	5	EPA 3050B/6010B
		Tl	< 10	mg/kg	10	EPA 3050B/6010B
		V	80	mg/kg	2	EPA 3050B/6010B
		Zn	1600	mg/kg	3	EPA 3050B/6010B

Metals Analysis of Bulks

Winzler & Kelly
Butch Reynolds
2 84 Teagarden St.

San Leandro, CA 94577

Client ID:	2735
Report Number:	M071393
Date Received:	06/21/05
Date Analyzed:	06/28/05
Date Printed:	06/29/05
First Reported:	06/29/05

Job ID / Site: 1030205001 - Steam Schooner `Wapama`

FASI Job ID: 2735-128

Sample Number	Lab Number	Analyte	Result	Result Units	Reporting Limit	Method Reference
T 2-2	30230364	Ag	< 0.5	mg/kg	0.5	EPA 3050B/6010B
		As	31	mg/kg	3	EPA 3050B/6010B
		Ba	340	mg/kg	10	EPA 3050B/6010B
		Be	< 0.5	mg/kg	0.5	EPA 3050B/6010B
		Cd	6	mg/kg	1	EPA 3050B/6010B
		Co	84	mg/kg	1	EPA 3050B/6010B
		Cr	220	mg/kg	2	EPA 3050B/6010B
		Cu	110	mg/kg	2	EPA 3050B/6010B
		Hg	2.3	mg/kg	0.2	EPA 7471A
		Mo	< 3	mg/kg	3	EPA 3050B/6010B
		Ni	3	mg/kg	3	EPA 3050B/6010B
		Pb	64000	mg/kg	200	EPA 3050B/6010B
		Sb	< 3	mg/kg	3	EPA 3050B/6010B
		Se	< 5	mg/kg	5	EPA 3050B/6010B
		Tl	< 10	mg/kg	10	EPA 3050B/6010B
		V	5	mg/kg	2	EPA 3050B/6010B
		Zn	4700	mg/kg	3	EPA 3050B/6010B

Dave Sandusky, Laboratory Supervisor, Hayward Laboratory

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Forensic Analytical #2735 - 128 Analysis Request Form

lient Name & Address: WINZLER & KELLY 2984 TEAGARDEN ST. SAN LEANDRO, CA 94577	P.O. #: 103020501 Date: 6 / 21 / 05 Turn Around Time: 5 DAY hr / 12hr / 24hr / 48 hr / ext: ___ Due Date: 6 / 28 / 05 Due Time: ___ : ___ am/pm ☐ FLM: ☐ Standard / ☐ Point Count ☐ PCM: NIOSH 7400
Contact: BUTCH REYNOLDS Phone #: (510) 667- 6440 Fax#: (510) 667- 6444	☐ TEM Air: ☐ AHERA / ☐ Yamate2 / ☐ NIOSH 7402 ☐ TEM Bulk: ☐ Quantitative / ☐ Qualitative / ☐ Chatfield ☐ TEM Water: ☐ Potable / ☐ Non-Potable / ☐ Wt % ☐ TEM Microvac ☐ Special Project:
Site: STEAM SCHOONER "WAPAMA" Job:	☒ Metals Analysis: Method ICP/Hg by Cold Vapor Matrix: BULK - CAM 17 - Title 22 Analytes: CAM 17

Comments: Composite Samples - Please Homogenize

Sample ID	Date/ Time	Sample Location/Description	FOR AIR SAMPLES ONLY				Sample Area or Air Volume
			Type	Time On/Off	Avg. LPM	Total Time	
T22 - 1		BOTTOM PAINT	A P C				
T22 - 2		BOAT DECK PAINT - (STARBOARD SIDE) WHITE	A P C				
			A P C				
			A P C				
			A P C				
			A P C				
			A P C				
			A P C				
			A P C				
			A P C				

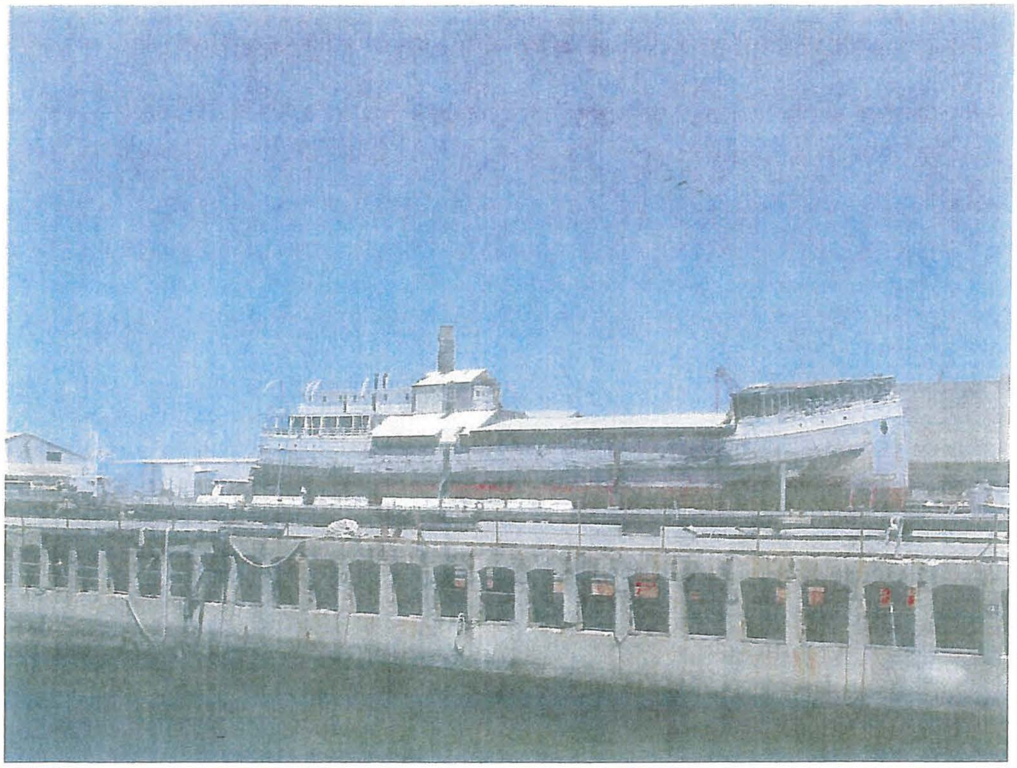
Sampled by: L. S. Reynolds Date: 6 / 14 / 05 Time: ___

Shipped via: ☐ Fed Ex ☐ Airborne ☐ UPS ☐ US Mail ☐ Courier ☐ Drop Off ☐ Other:

Relinquished by: Date / Time: 6/21/05	Relinquished by: Date / Time:	Relinquished by: Date / Time:
Received by: Date / Time: 06/21/05 1PM Condition Acceptable? ☑ Yes ☐ No	Received by: Date / Time: Condition Acceptable? ☐ Yes ☐ No	Received by: Date / Time: Condition Acceptable? ☐ Yes ☐ No

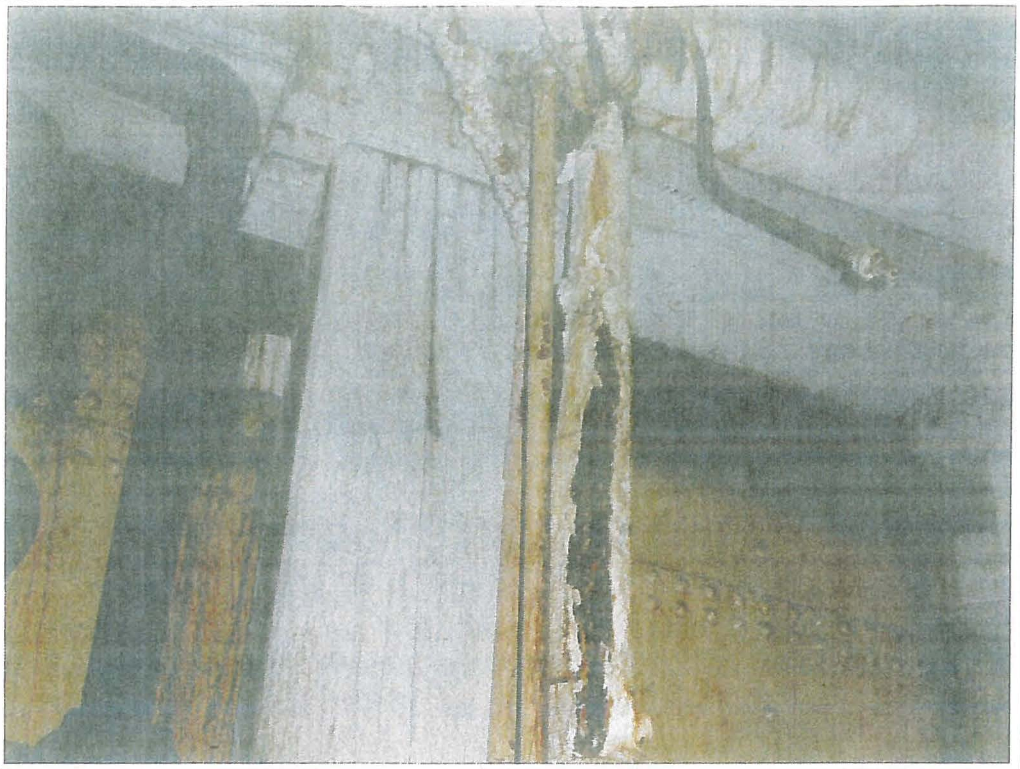
SECTION 5

PHOTOGRAPHICS

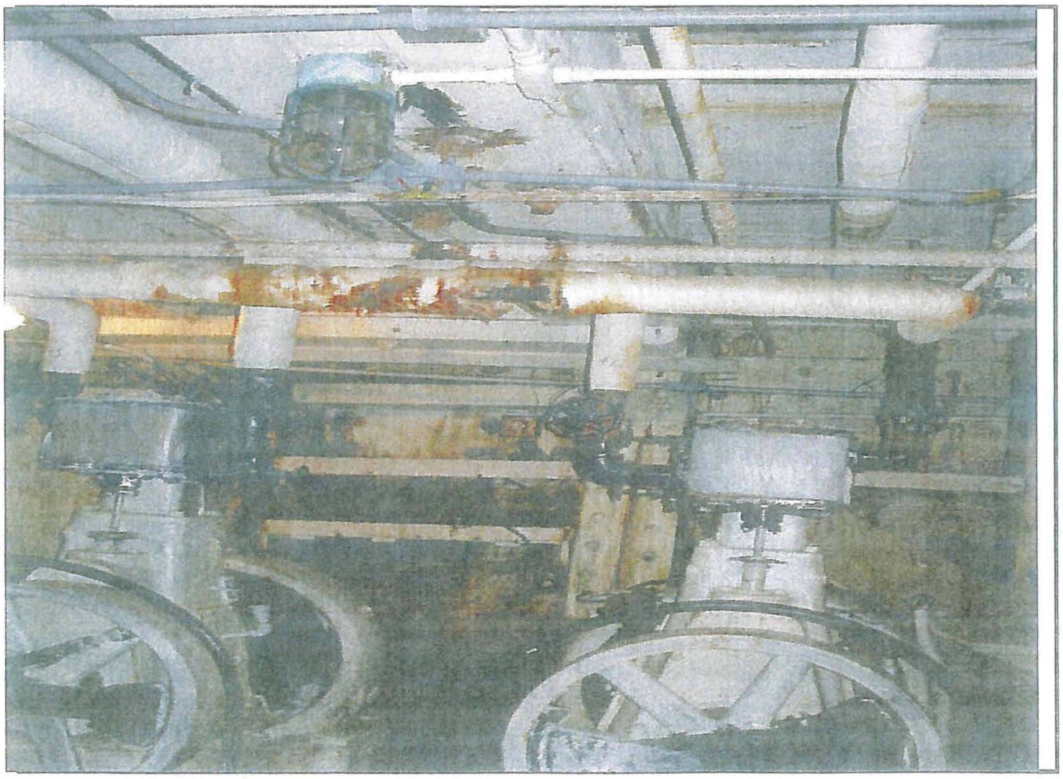


MATERIAL: SS WAPAMA, STBD VIEW – DETERIATED EXTERIOR PAINT
CONTAMINANT: LEAD CONTAINING AND TOXIC MATERIALS

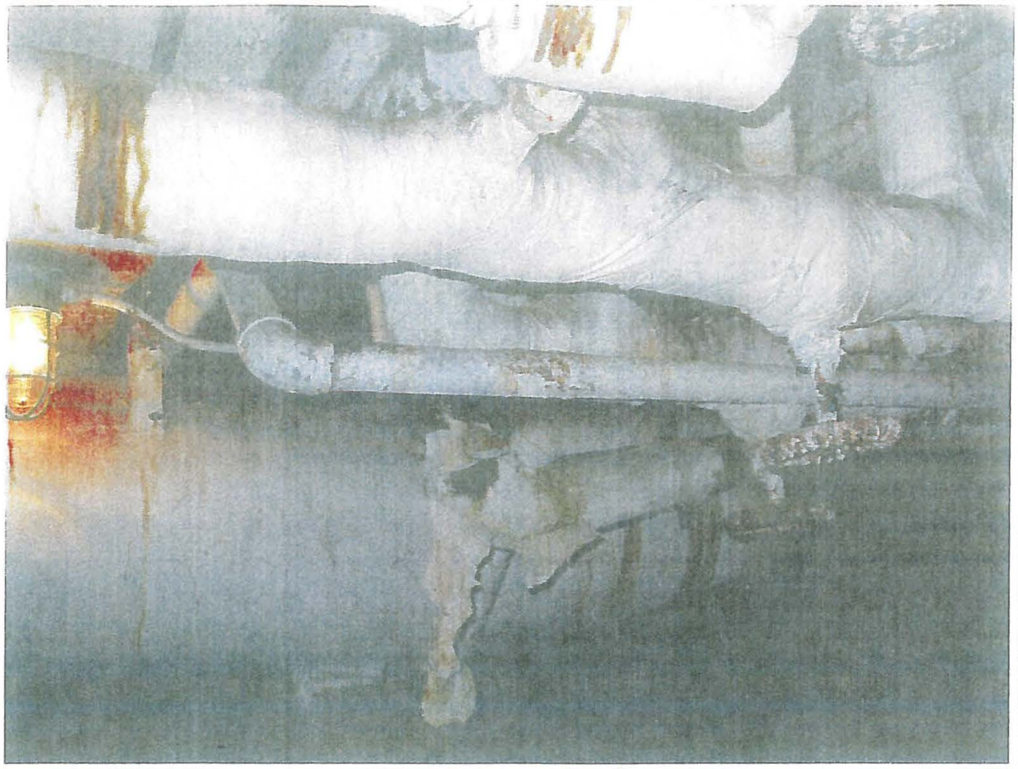
MATERIAL: PIPE RISER WITH DAMAGED INSULATION
CONTAMINANT: ASBESTOS



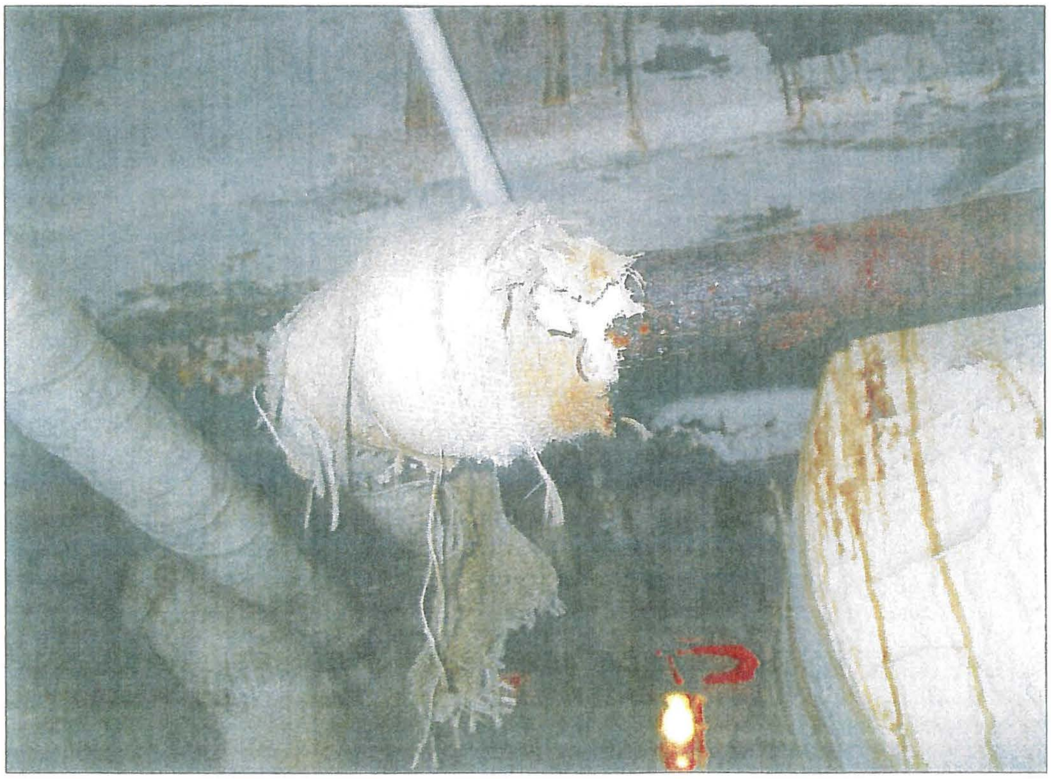
MATERIAL: PIPE RISER WITH DAMAGED INSULATION
CONTAMINANT: ASBESTOS



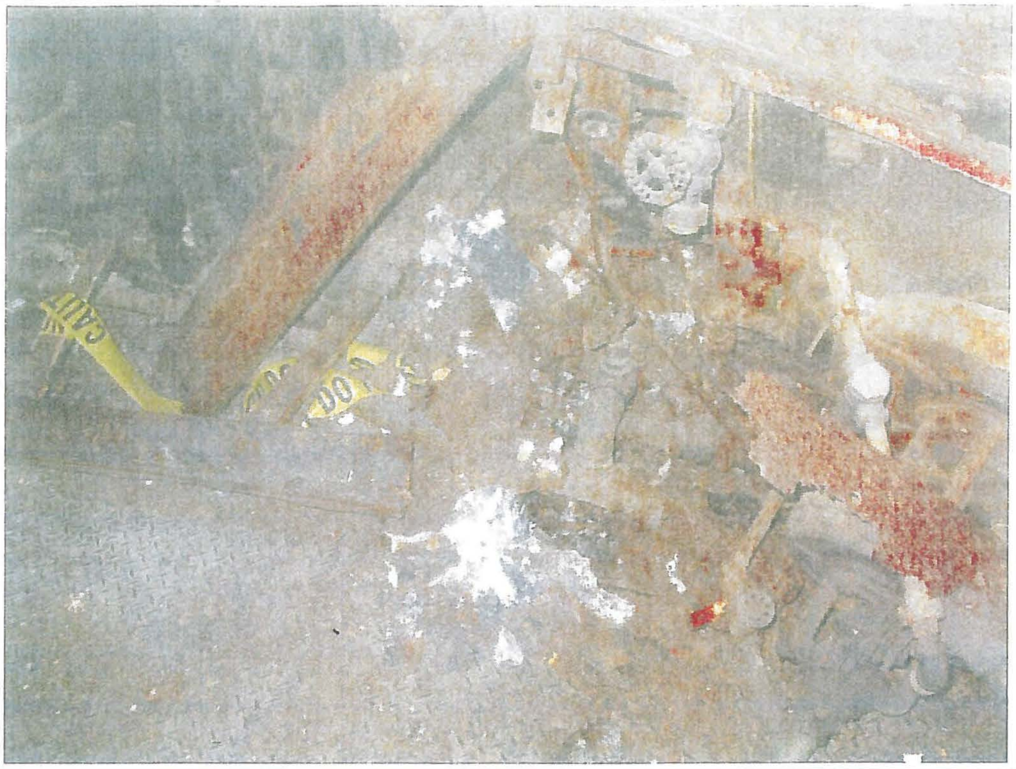
MATERIAL: PIPE INSULATION (DAMAGED) OVER GENERATORS (PORT SIDE)
CONTAMINANT: ASBESTOS



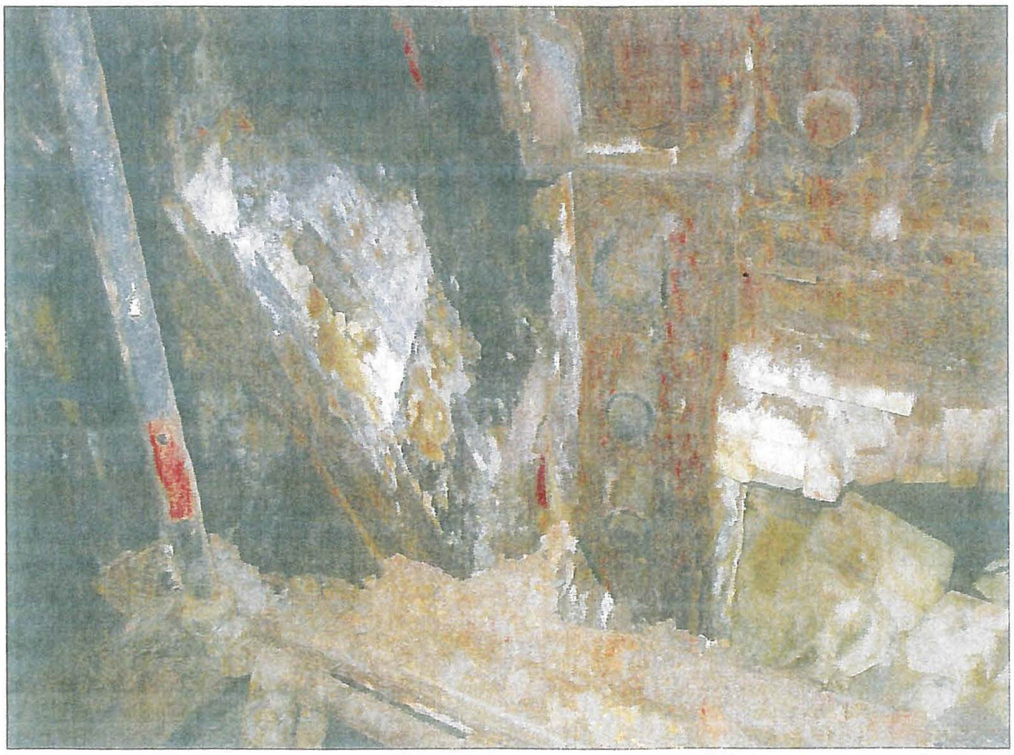
MATERIAL: PIPE INSULATION AT WATER TANK
CONTAMINANT: ASBESTOS



MATERIAL: PIPE INSULATION, DAMAGED
CONTAMINANT: ASBESTOS



MATERIAL: BOILER INSULATION DEBRIS, STBD FIRE BOX AT DECK
CONTAMINANT: ASBESTOS



MATERIAL: BOILER INSULATION, STBD FIRE BOX AT BOILER
CONTAMINANT: ASBESTOS

CONDITION ASSESSMENT OF MAIN STRUCTURAL MEMBERS OF

WAPAMA

- A Historic Steam Schooner

Natural Resources Research Institute
University of Minnesota Duluth
Duluth, Minnesota
February 2006

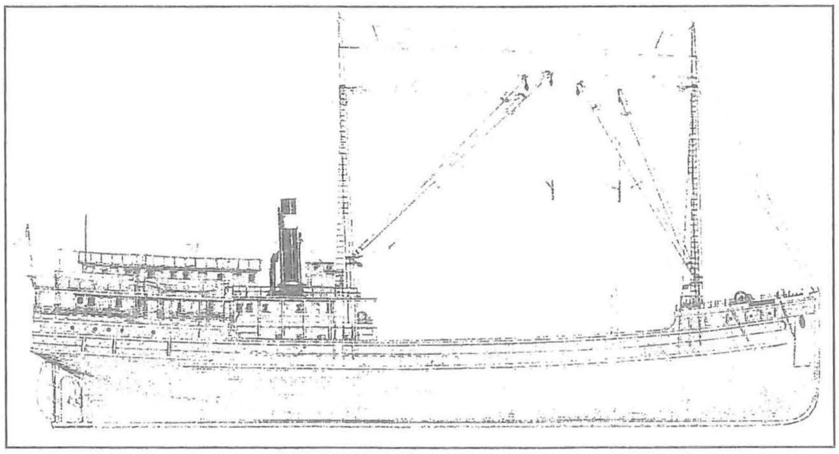
CONDITION ASSESSMENT OF MAIN STRUCTURAL MEMBERS OF WAPAMA

By

Xiping Wang, Ph.D.
Natural Resources Research Institute
University of Minnesota Duluth

James P. Wacker, P.E.
Crystal Pilon
Robert J. Ross, Ph.D.
USDA Forest Service, Forest Products Laboratory

Brian K. Brashaw, Program Director
NRRI, University of Minnesota Duluth



February 2006
Project No. 187-6530
NRRI/TR-2006/03

Natural Resources Research Institute
University of Minnesota Duluth
5013 Miller Trunk Highway
Duluth, MN 55811

Prepared for:
Architectural Resources Group
Pier 9, The Embarcadero
San Francisco, CA 94111

List of Tables

Table 1. Deterioration in assistant keelson revealed by Resistograph tests.

Table 2. Stress wave transmission time (SWTT) and physical conditions of the portside main deck beams and hanging knees.

Table 3. Physical conditions of the pillars evaluated by stress wave tests.

1. Preface

The historic American ship WAPAMA is the last surviving example of the wooden steam-powered schooners designed for the 19th and 20th century Pacific Coast lumber trade and coastal service. Since her launching in 1915, the WAPAMA has had a long and productive life in plying cargo and passengers along the stormy West Coast from Mexico to Alaska. As the sole survivor of the once numerous class, the WAPAMA was declared as a National Historic Landmark (NHL) in 1984.

The wood structure of the WAPAMA has been significantly deteriorated over the years and currently resides on a barge with internal and external structural supports. Portions of the vessel are unsafe for public access. To assist in an effort of stabilizing and rehabilitating this historic vessel, we conducted a field investigation on the current physical condition of the wooden structural members. A variety of nondestructive testing (NDT) methods were employed to locate problem areas and define the severity of deteriorations on key structural members such as keelsons, keel, ceiling planking, hull frames, clamps, and main deck beams etc. This report presents the main findings from this field investigation and demonstrates the use of the state-of-the-art NDT technologies in evaluating physical and biological conditions of historic wood structures.

In 1980, the vessel can no longer remain afloat due to severe deterioration and was hauled out of water and placed on Barge 214, berthed at Pacific Drydock Co., Alameda. Since that time she has remained on the barge and received limited maintenance. Currently, the vessel resides on Barge 214 in a flooded graving dock at the Richmond Reserve Shipyard in Richmond, California and is unsafe for public access (Figure 2).

In an effort to stabilize and rehabilitate the vessel, the National Park Service tasked the Architectural Resources Group (ARG) to undertake a condition assessment of the vessel and provide preservation recommendations.

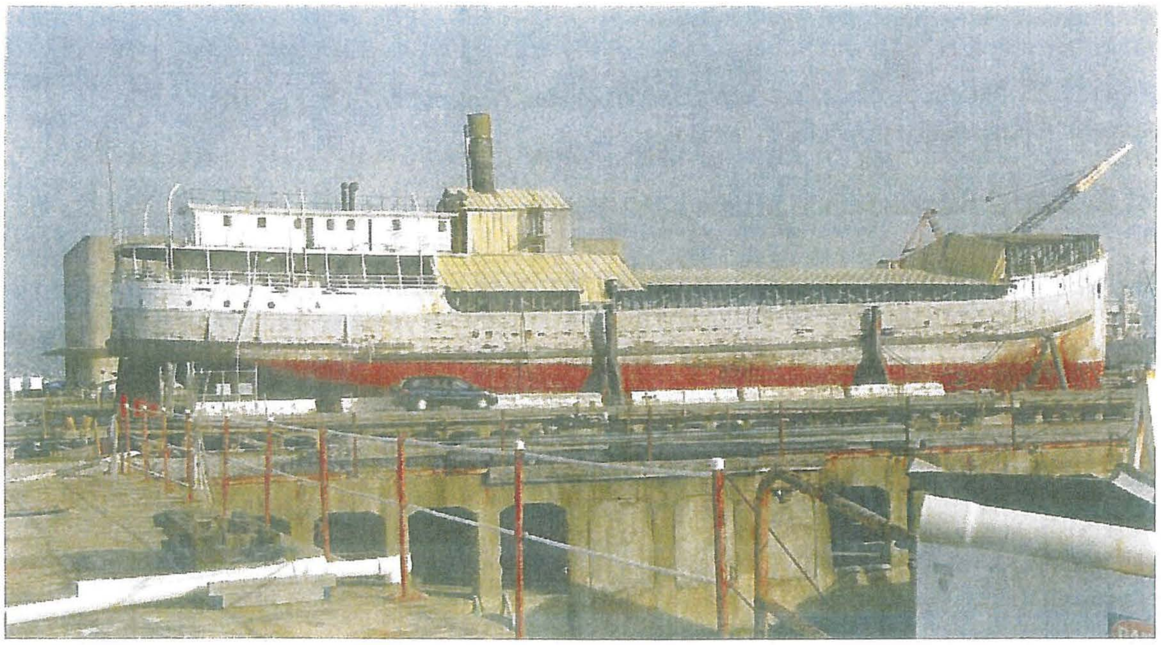


Figure 2. A recent photo of the WAPAMA placed on Barge 214 at Richmond Reserve Shipyard in Richmond, California (Photo taken on January 2006).

3. Scope of Work

In response to the request from the Architectural Resources Group (ARG), an architectural firm based in San Francisco, CA, the Natural Resources Research Institute (NRRI) at University of Minnesota Duluth has signed a cooperative research agreement with the ARG for conducting an on-site condition assessment of key wooden structural members of the vessel. This work is aimed to assist a structural engineering analysis process on determining the possibility of stabilizing and rehabilitating the vessel.

In a recent condition survey of the vessel and barge, BMT Designers & Planners, Inc. provided visual assessment in terms of safety and stability of the vessel and conducted a preliminary structural analysis of the vessel's main features and support structures. The intent of this on-site investigation was to physically test the key wooden structure evaluation methods that were employed in our investigation are 1) stress wave (acoustic wave) transmission technique and 2) resistance micro-drilling technique.

4.1 Stress Wave Transmission Technique

Stress wave transmission technique has been successfully used in decay detection in a variety of wood structures (Forest Products Laboratory 2000). The concept of detecting decay using this method is that stress wave propagation is sensitive to the presence of degradation in wood. In general terms, a stress wave travels faster through sound and high quality wood than it does through wood that is deteriorated or of low quality. The time-of-flight (or transmission time) of the stress wave is typically used as a predictor of the physical conditions inside the wood. By measuring the time-of-flight of a stress wave through wood member perpendicular to grain, the internal condition of the member could be determined. Detailed information on the principles of stress wave transmission technique and the guidelines for use and interpretation are given in FPL-GTR-119 (Appendix E).

4.2 Resistance Micro-Drilling

Resistance micro-drilling is also called Resistograph test. This method is being used increasingly in the field to characterize wood properties and detecting abnormal physical conditions in structural timbers. The Resistograph tool is a mechanical drill system that measures the relative resistance (drilling torque) of the material as a rotating drill bit is driven into the wood at a constant speed. It produces a chart showing the relative resistance profile for each drill path. Because it can reveal the relative density change along the drill path, it is typically used to diagnose the internal condition of structural timbers.

The drill resistance R_D is defined as

$$R_D = \frac{T}{\omega} \qquad \text{(Nm s/rad)}$$

where T is drilling torque (Nm), ω is the angular speed (rad/s).

A Resistograph tool typically consists of a power drill unit, a small-diameter drill bit, a paper chart recorder, and an electronic device that can be connected to the serial interface input of any standard PC. The diameter of the drill bit is typically very small, from 2 to 5 mm, so that any weakening effect of the drill hole on the wood cross section is negligible.

5. Inspection Procedure

5.1 General Procedure

On-site inspection of the WAPAMA was conducted by the inspection team between January 10 and 13, 2006. Following general procedure was followed during the inspection:

- Identify critical areas and key structural elements (sampling);

5.3 Micro-Drilling Test

A Resistograph tool (IML-RESI F400) was used to conduct micro-drilling tests and obtain relative resistance profiles for the key structure elements. The purpose of conducting micro-drilling test was two-folds: 1) to confirm and determine the extent of the decay in critical locations or areas that have been identified by stress wave scanning; and 2) to determine the internal conditions of the key structure elements that can not be scanned using stress wave transmission techniques.

The drill was oriented so that its drilling path was perpendicular to the exposed face of the wood members. During each dill test, the relative resistance was recorded on a wax paper graph and also stored in an electronic unit. Each resistance chart was properly coded to track its drilling location in a specific member. The electronic files were transmitted to a computer after testing for further analysis. The maximum drilling depth of the tool we used is 15 inches, so the internal condition of wood beyond this depth can not be revealed.

Ceiling planks, assistant keelsons, hull frames, clamps, waterways, bulwark, and assistant stringers are the key strength members that cannot be evaluated with stress wave transmission techniques. To assess the physical conditions of these members, we selected three main sections along the length of the vessel for detail inspection with the Resistograph tool (Figure 1). The three sections selected are 1) section at frame 8; 2) section at frame 32; and 3) section at frame 48. The drilling locations at these sections are illustrated in Figures 4, 5, and 6.

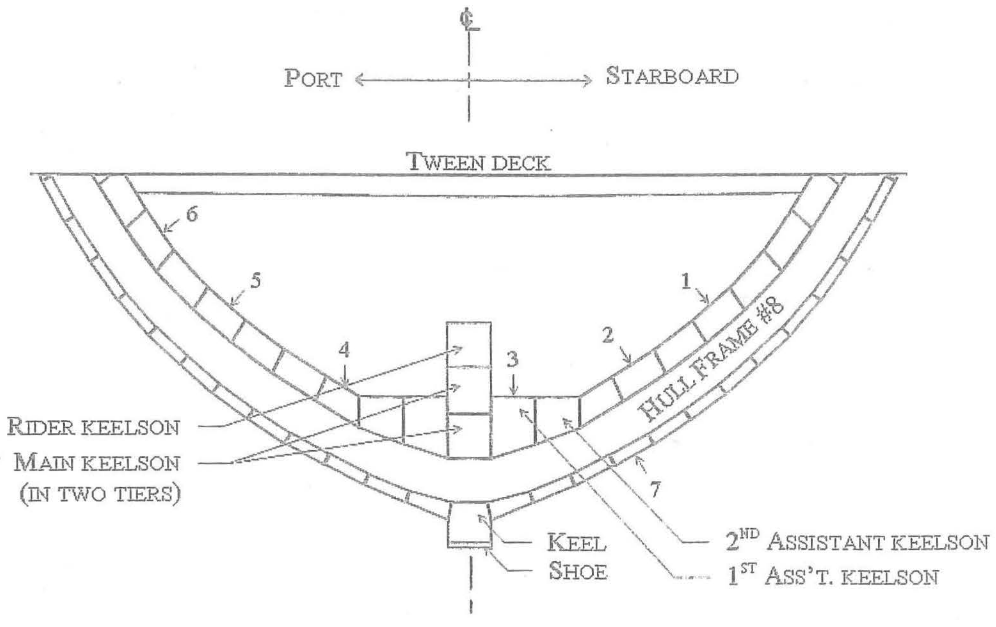


Figure 4. Schematic of drilling locations for the cross-section at frame 8.

In assisting the on-site inspection efforts, we also took a series of photographs and short videos to document the inspection process and the physical conditions of the key structure features. Photos are shown in Appendix A. Videos are recorded in a DVD accompanied with the report.

6. Main Findings

6.1 Keelsons

Keelsons are key longitudinal strength members and form the main backbone of the vessel. The keelson members in the WAPAMA include rider keelson (20 x 17 ½ in.), main keelson (20 x 37 in. in two tiers), and three assistant keelsons, port and starboard. The rider keelson and part of the main keelson (upper portion) are exposed above the top surface of the assistant keelsons and therefore are readily available for stress wave scanning. The assistant keelsons, on the other hand, only have the top face exposed. Therefore the internal condition of the assistant keelsons can only be evaluated through micro-drilling tests.

6.1.1 Rider Keelson and Main Keelson

The rider keelson and main keelson (above the top surface of the assistant keelsons) in the cargo hold were stress wave scanned along three lines (Figure 3a). Line A and B were on the rider keelson and line C was on the main keelson. The portion of the keelsons tested is between frame 7 and 48. The keelsons beyond this portion were not tested due to lack of access or difficulty to access.

Figure 7 illustrated the distribution of stress wave transmission time (SWTT) (unit: μs/ft) along the length as well as the mapping of physical conditions of the rider keelson and main keelson. The physical conditions of each test location were rated into four categories by comparing the measured SWTT with the reference SWTT and color-coded as the following:

🟨	Solid:	< 300 μs/ft
🟦	Moderate decay:	300 - 600 μs/ft
🟥	Decay:	600 - 900 μs/ft
🟫	Severe decay:	> 900 μs/ft

The deterioration of the keelsons is concentrated between frame 25 and 42 and most severe decay occurred on the main keelson timber between frame 30 and 39. This is also confirmed by resistance micro-drilling tests (Appendix C1). It is likely that rainwater got into this area through the hatch over the years due to failed weather protection and water remained trapped. The water damage in untested portion of the main keelson between frame 30 and 39 and even beyond could also be significant. Deterioration could be further extended and advanced with the current outdated weather protection.

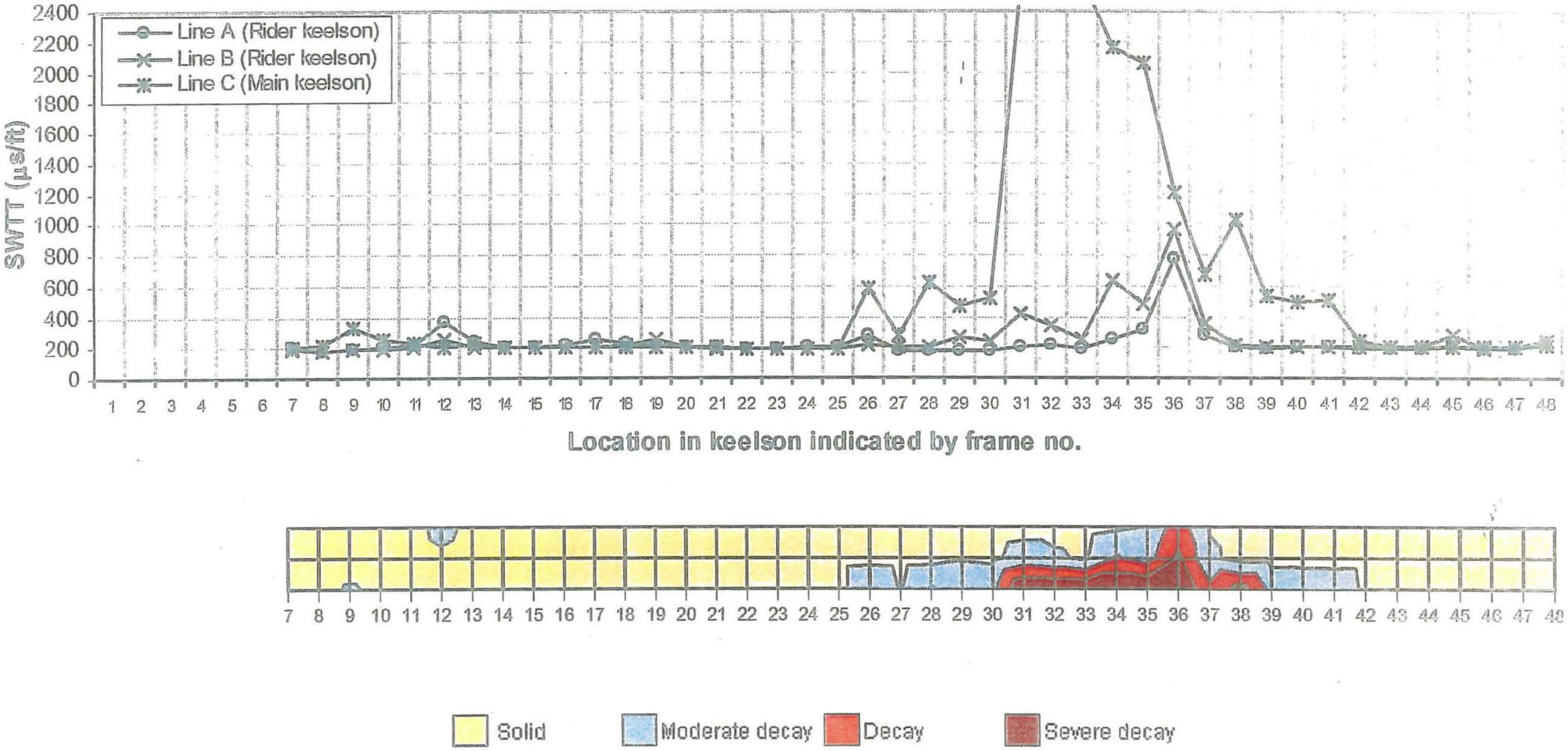


Figure 7. Distribution of stress wave transmission time (SWTT) and mapping of physical conditions of the keelsons.

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WAPAMA

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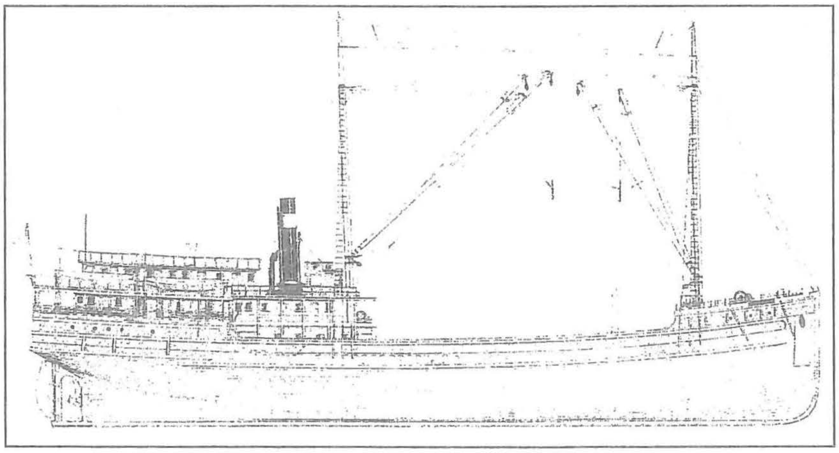

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List of Figures

Figure 1. Starboard elevation of the WAPAMA.

Figure 2. A recent photo of the WAPAMA placed on Barge 214 at Richmond Reserve Shipyard in Richmond, California.

Figure 3. Scanning diagram of longitudinal strength members – (a) keelsons; (b) keel; and (c) main deck stringer.

Figure 4. Schematic of drilling locations for the cross-section at frame 8.

Figure 5. Schematic of drilling locations for the cross-section at frame 32.

Figure 6. Schematic of drilling locations for the cross-section at frame 48.

Figure 7. Distribution of stress wave transmission time (SWTT) and mapping of physical conditions of the keelsons.

Figure 8. Distribution of stress wave transmission time (SWTT) and mapping of physical conditions of the keel.

Figure 9. Stress wave transmission time (SWTT) and physical conditions of the main deck stringers.

Figure 10. Mapping of physical conditions of the cross-section at frame 8 (Resistograph interpretation).

Figure 11. Mapping of physical conditions of the cross-section at frame 32 (Resistograph interpretation).

Figure 12. Mapping of physical conditions of the cross-section at frame 48 (Resistograph interpretation).

Figure 13. Stress wave testing locations for portside main deck beams.

Figure 14. Mapping of physical conditions of portside main deck beams (Plan view).

Figure 15. Location of pillars and stanchions on the ship (Plan view).

1. Preface

The historic American ship WAPAMA is the last surviving example of the wooden steam-powered schooners designed for the 19th and 20th century Pacific Coast lumber trade and coastal service. Since her launching in 1915, the WAPAMA has had a long and productive life in plying cargo and passengers along the stormy West Coast from Mexico to Alaska. As the sole survivor of the once numerous class, the WAPAMA was declared as a National Historic Landmark (NHL) in 1984.

The wood structure of the WAPAMA has been significantly deteriorated over the years and currently resides on a barge with internal and external structural supports. Portions of the vessel are unsafe for public access. To assist in an effort of stabilizing and rehabilitating this historic vessel, we conducted a field investigation on the current physical condition of the wooden structural members. A variety of nondestructive testing (NDT) methods were employed to locate problem areas and define the severity of deteriorations on key structural members such as keelsons, keel, ceiling planking, hull frames, clamps, and main deck beams etc. This report presents the main findings from this field investigation and demonstrates the use of the state-of-the-art NDT technologies in evaluating physical and biological conditions of historic wood structures.

2. Background

The vessel WAPAMA was built in 1915 and is the last surviving example afloat of some 225 steam schooners specifically designed for use in the 19th and 20th century Pacific Coast lumber trade and coastwise service (Tri-Coastal Marine, Inc. 1986). These vessels formed the backbone of maritime trade and commerce on the west coast ferrying lumber, general cargo, and passengers to and from urban centers and smaller coastal settlements. The men who built them took advantage of plentiful timber and built ships out of wood, long after builders in most of the Western world had shifted to iron and steel construction. These wooden ships were a mainstay of the coastwise carrying trade for decades. As the sole survivor of the once numerous class, the WAPAMA was declared as a National Historic Landmark (NHL) in 1984 due to the international, national, and regional significance.

The WAPAMA is built almost entirely of old growth Douglas-fir timber, and is approximately 217 feet long and 50 feet from keel to house top, with a gross tonnage of 945 GT. The construction is unique in its use of sister frames and lack of steel strapping. The hull is single decked and characterized by a plumb stem, full bows, straight keel, moderate deadrise and an easy turn of bilge (Figure 1).

In 1979, the vessel was removed from her berth at the California State Historical Maritime Park at Hyde Street Pier and moved to a submarine pen at Hunter Point Naval Shipyard. This move to quiet water was to minimize stress on the hull. Prior to building a breakwater in the mid 1980's, the Hyde Street Pier resembled an ocean pier more than a bay pier. Winter storms, in particular, were extremely stressful on the entire fleet.

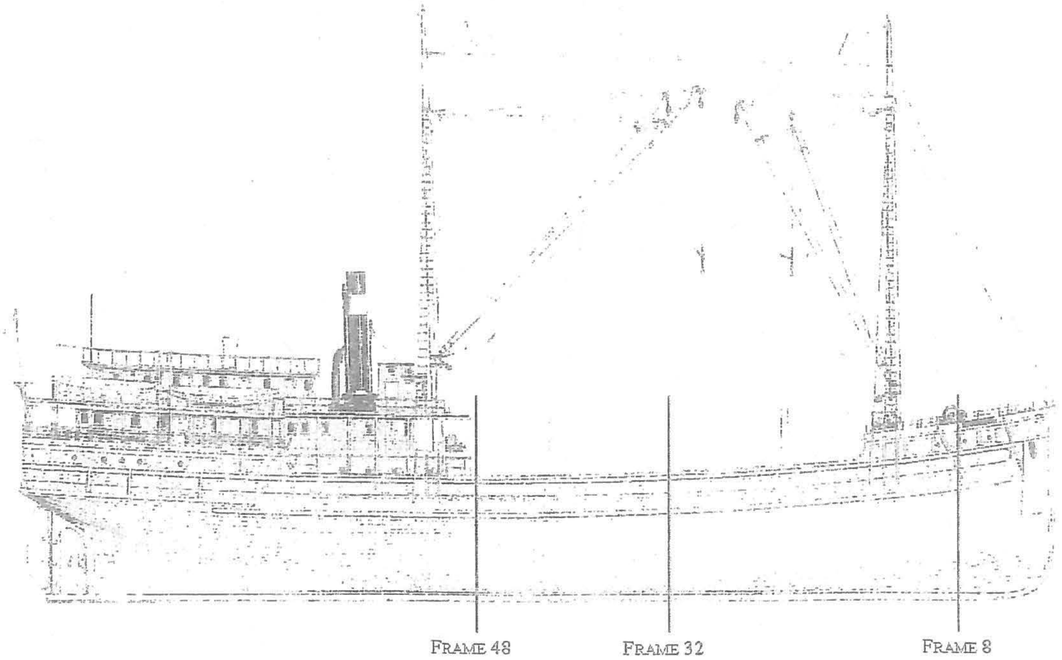


Figure 1. Starboard elevation of the WAPAMA.

In 1980, the vessel can no longer remain afloat due to severe deterioration and was hauled out of water and placed on Barge 214, berthed at Pacific Drydock Co., Alameda. Since that time she has remained on the barge and received limited maintenance. Currently, the vessel resides on Barge 214 in a flooded graving dock at the Richmond Reserve Shipyard in Richmond, California and is unsafe for public access (Figure 2).

In an effort to stabilize and rehabilitate the vessel, the National Park Service tasked the Architectural Resources Group (ARG) to undertake a condition assessment of the vessel and provide preservation recommendations.

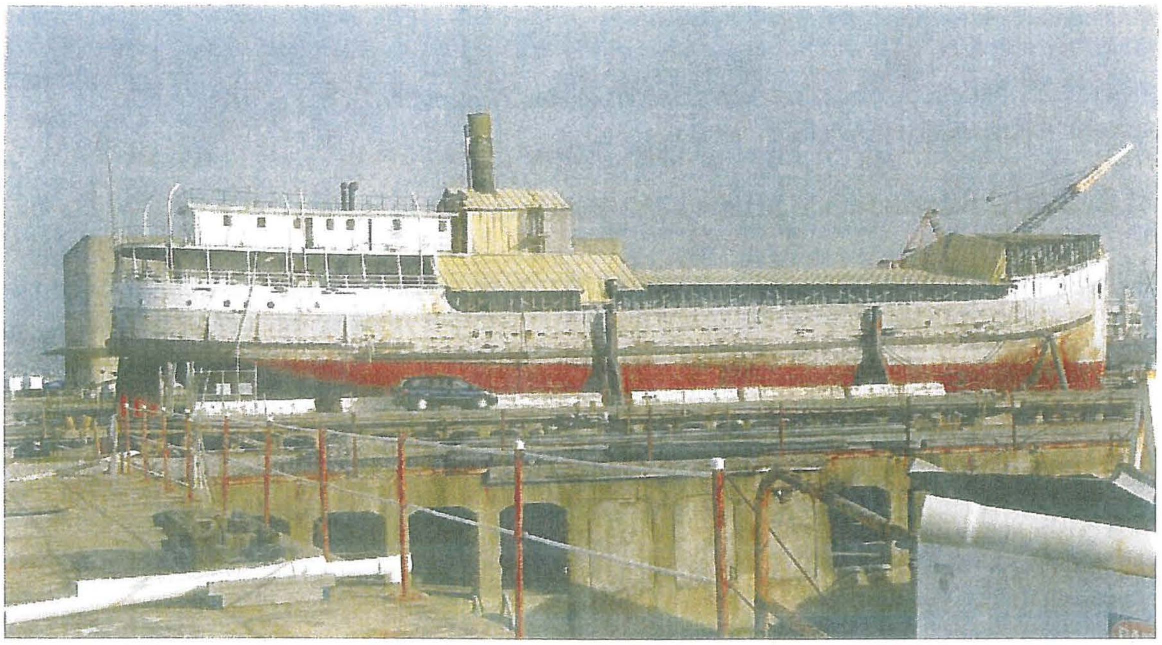


Figure 2. A recent photo of the WAPAMA placed on Barge 214 at Richmond Reserve Shipyard in Richmond, California (Photo taken on January 2006).

3. Scope of Work

In response to the request from the Architectural Resources Group (ARG), an architectural firm based in San Francisco, CA, the Natural Resources Research Institute (NRRI) at University of Minnesota Duluth has signed a cooperative research agreement with the ARG for conducting an on-site condition assessment of key wooden structural members of the vessel. This work is aimed to assist a structural engineering analysis process on determining the possibility of stabilizing and rehabilitating the vessel.

In a recent condition survey of the vessel and barge, BMT Designers & Planners, Inc. provided visual assessment in terms of safety and stability of the vessel and conducted a preliminary structural analysis of the vessel's main features and support structures. The intent of this on-site investigation was to physically test the key wooden structure elements that were deemed structurally in critical state or unknown condition and provide scientific evidence of WAPAMA's deterioration.

On January 10, 2006, the first day on WAPAMA, the inspection team had a meeting with the following personnel who are involved in the preservation project:

Gee Hechscher, Structural Engineer, Architectural Resources Group.

Steve Hyman, Historic Preservation Specialist, San Francisco Maritime NHP, National Park Service.

Allen C. Rawl, President, Allen C. Rawl, Inc.

Trung-Son T. Nguyen, Architect, Pacific Great Basin Support Office, Facility Management Team, National Park Service.

Michael R. Bell, San Francisco Maritime NHP, National Park Service.

Per the discussion in this meting, we decided that our NDE inspection should be focused on the key strength members. With the input from Mr. Steve Hyman and Mr. Allen Rawl, we identified following features as priority target for a four-day-long on-site inspection:

1. Keelsons
2. Assistant keelsons
3. Keel
4. Ceiling planks
5. Hull frames
6. Clamps
7. Main deck beams
8. Main deck stringers
9. Waterways
10. Hanging knees
11. Pointers
12. Main supporting columns

4. Inspection Methodology

The general physical condition of the WAPAMA has been assessed and monitored at periodic intervals since the acquisition of the vessel by the State Maritime Historical Park in 1957. The inspection in previous surveys and studies were mostly done by visual observation and wood borings. The in-depth information on the deterioration levels of structure elements is limited. The focus of this investigation was to nondestructively determine the internal physical condition of the key structural elements of the vessel that are usually difficult to assess by visual inspection. Two state-of-the-art nondestructive evaluation methods that were employed in our investigation are 1) stress wave (acoustic wave) transmission technique and 2) resistance micro-drilling technique.

4.1 Stress Wave Transmission Technique

Stress wave transmission technique has been successfully used in decay detection in a variety of wood structures (Forest Products Laboratory 2000). The concept of detecting decay using this method is that stress wave propagation is sensitive to the presence of degradation in wood. In general terms, a stress wave travels faster through sound and high quality wood than it does through wood that is deteriorated or of low quality. The time-of-flight (or transmission time) of the stress wave is typically used as a predictor of the physical conditions inside the wood. By measuring the time-of-flight of a stress wave through wood member perpendicular to grain, the internal condition of the member could be determined. Detailed information on the principles of stress wave transmission technique and the guidelines for use and interpretation are given in FPL-GTR-119 (Appendix E).

4.2 Resistance Micro-Drilling

Resistance micro-drilling is also called Resistograph test. This method is being used increasingly in the field to characterize wood properties and detecting abnormal physical conditions in structural timbers. The Resistograph tool is a mechanical drill system that measures the relative resistance (drilling torque) of the material as a rotating drill bit is driven into the wood at a constant speed. It produces a chart showing the relative resistance profile for each drill path. Because it can reveal the relative density change along the drill path, it is typically used to diagnose the internal condition of structural timbers.

The drill resistance R_D is defined as

$$R_D = \frac{T}{\omega} \qquad \text{(Nm s/rad)}$$

where T is drilling torque (Nm), ω is the angular speed (rad/s).

A Resistograph tool typically consists of a power drill unit, a small-diameter drill bit, a paper chart recorder, and an electronic device that can be connected to the serial interface input of any standard PC. The diameter of the drill bit is typically very small, from 2 to 5 mm, so that any weakening effect of the drill hole on the wood cross section is negligible.

5. Inspection Procedure

5.1 General Procedure

On-site inspection of the WAPAMA was conducted by the inspection team between January 10 and 13, 2006. Following general procedure was followed during the inspection:

- Identify critical areas and key structural elements (sampling);

- Examine moisture content (moisture meter);
- Perform stress wave scanning tests in key strength members (Fakopp Microsecond Timer);
- Perform resistance micro-drilling tests on key strength members (Resistograph tool).
- Photographic documentation of inspection process and ship conditions.

Stress wave scanning and resistance micro-drilling were two primary means we used to determine the internal physical conditions of the wood members.

5.2 Stress wave scanning

Stress wave transmission test requires access of two opposite sides of a timber for attaching sensor probes. Therefore, the stress wave scanning in the WAPAMA was only conducted on the structural members that have both sides exposed and are within the reach of the inspectors. Such members included keelsons, keel, stringers, main deck beams, vertical supporting members, pointers, and hanging knees. Stress wave transmission tests were performed on these members using a Fakopp Microsecond Timer.

For the longitudinal strength members such as keelsons, assistant keelsons, keel, and main deck stringers, stress wave transmission tests (perpendicular to grain) were conducted along one, two, or three lines on the side surface. The intervals between two scanning points in the longitudinal direction varied for different members: 2 ½ ft for keelsons, 5 to 6 ft for keel and main deck stringers. Figure 3 shows a typical scanning diagram for inspecting and mapping longitudinal members with stress wave transmission times.

For vertical supporting members, pointers, main deck beams, and hanging knees, stress wave transmission tests were conducted as a spot check due to the limited available time on the ship.

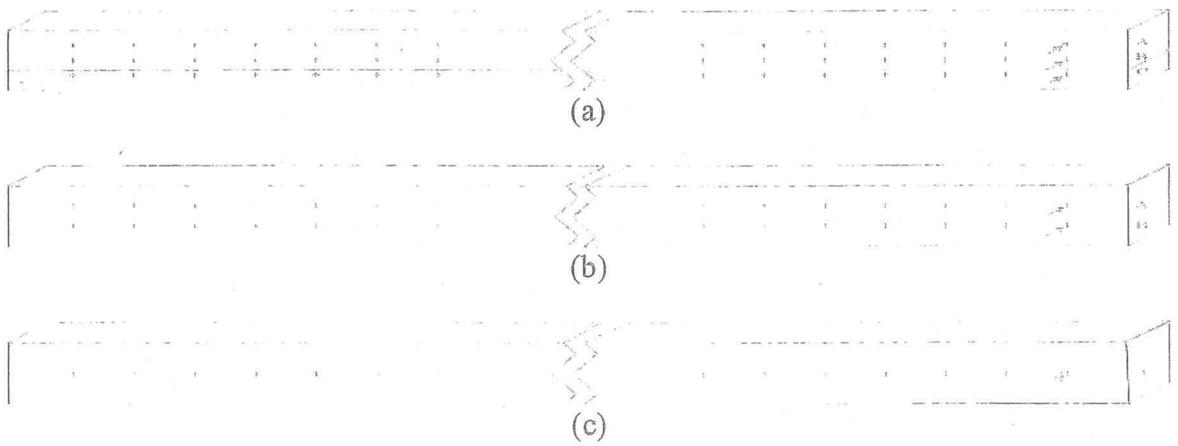


Figure 3. Scanning diagram of longitudinal strength members - (a) keelsons; (b) keel; and (c) main deck stringers.

5.3 Micro-Drilling Test

A Resistograph tool (IML-RESI F400) was used to conduct micro-drilling tests and obtain relative resistance profiles for the key structure elements. The purpose of conducting micro-drilling test was two-folds: 1) to confirm and determine the extent of the decay in critical locations or areas that have been identified by stress wave scanning; and 2) to determine the internal conditions of the key structure elements that can not be scanned using stress wave transmission techniques.

The drill was oriented so that its drilling path was perpendicular to the exposed face of the wood members. During each dill test, the relative resistance was recorded on a wax paper graph and also stored in an electronic unit. Each resistance chart was properly coded to track its drilling location in a specific member. The electronic files were transmitted to a computer after testing for further analysis. The maximum drilling depth of the tool we used is 15 inches, so the internal condition of wood beyond this depth can not be revealed.

Ceiling planks, assistant keelsons, hull frames, clamps, waterways, bulwark, and assistant stringers are the key strength members that cannot be evaluated with stress wave transmission techniques. To assess the physical conditions of these members, we selected three main sections along the length of the vessel for detail inspection with the Resistograph tool (Figure 1). The three sections selected are 1) section at frame 8; 2) section at frame 32; and 3) section at frame 48. The drilling locations at these sections are illustrated in Figures 4, 5, and 6.

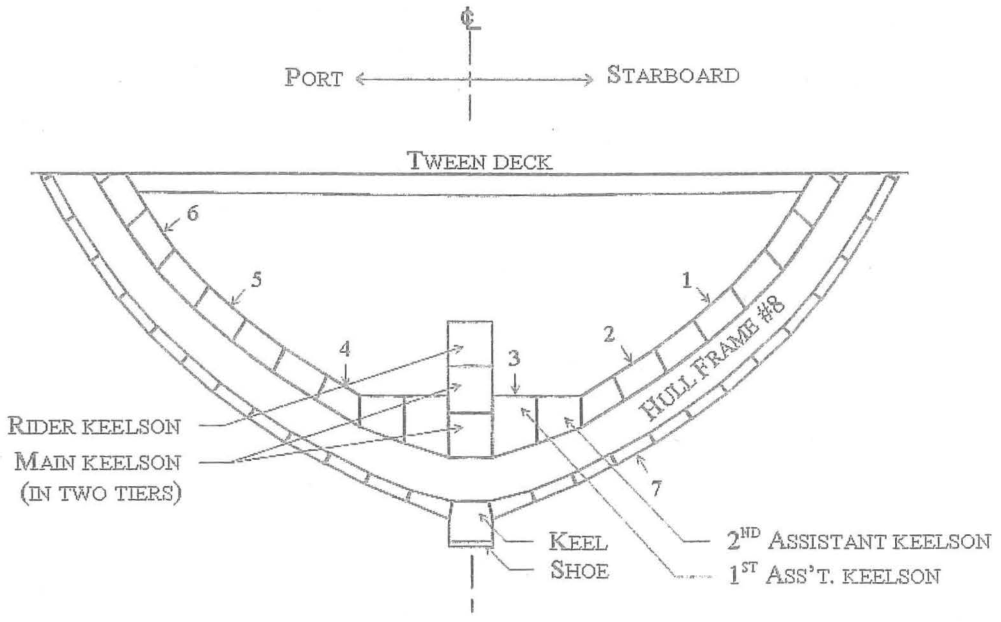


Figure 4. Schematic of drilling locations for the cross-section at frame 8.

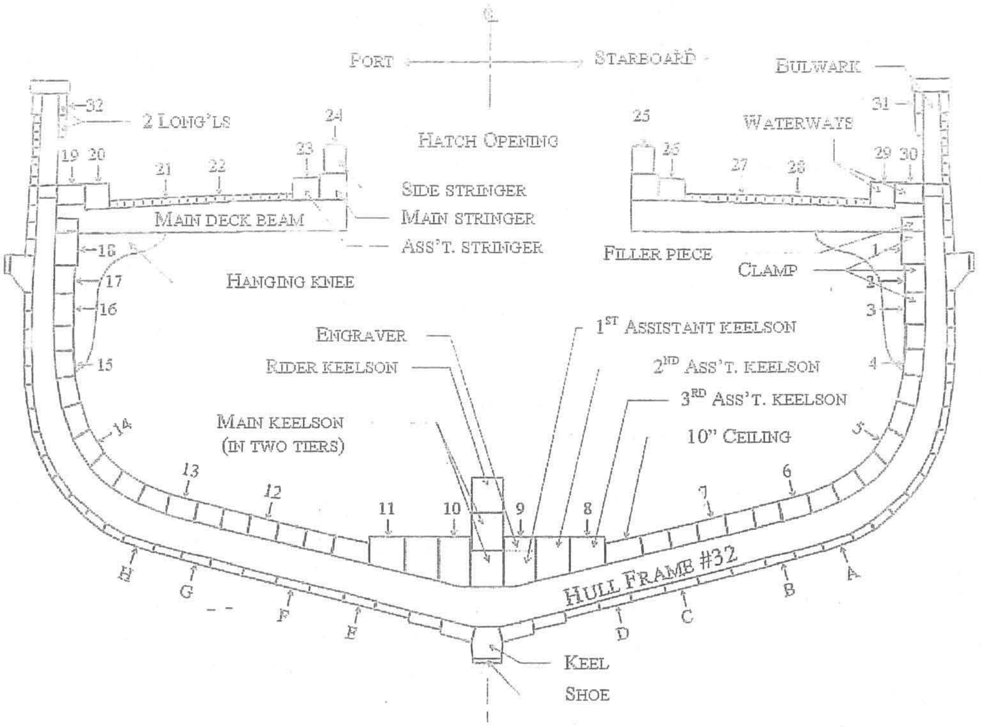


Figure 5. Schematic of drilling locations for the cross-section at frame 32.

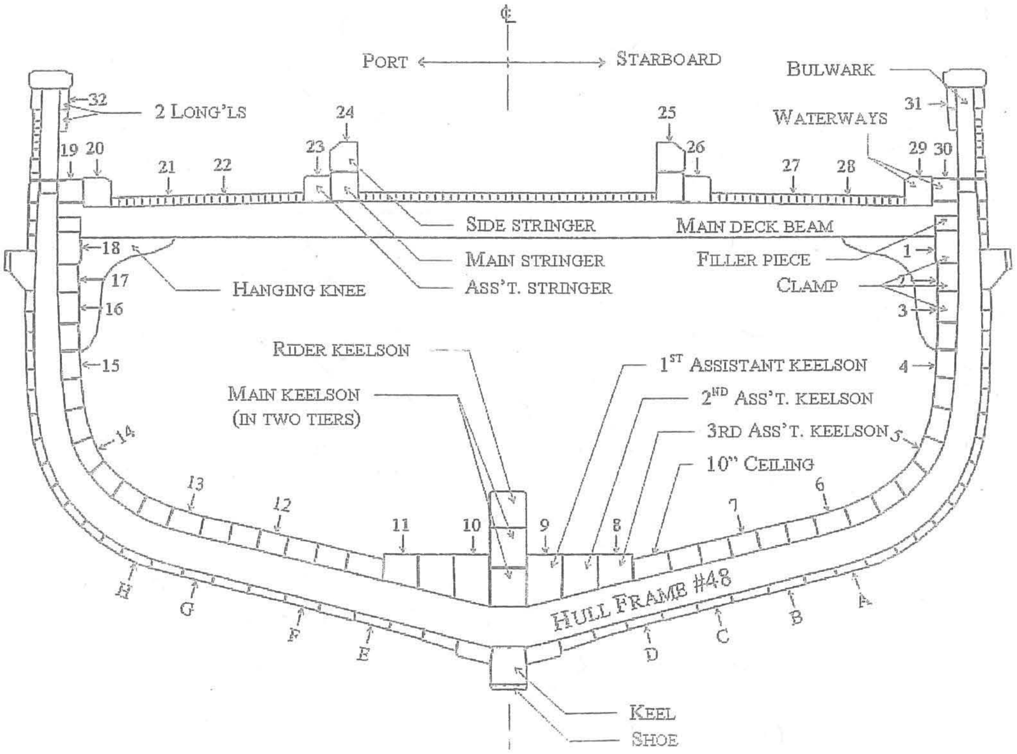


Figure 6. Schematic of drilling locations for the cross-section at frame 48.

In assisting the on-site inspection efforts, we also took a series of photographs and short videos to document the inspection process and the physical conditions of the key structure features. Photos are shown in Appendix A. Videos are recorded in a DVD accompanied with the report.

6. Main Findings

6.1 Keelsons

Keelsons are key longitudinal strength members and form the main backbone of the vessel. The keelson members in the WAPAMA include rider keelson (20 x 17 ½ in.), main keelson (20 x 37 in. in two tiers), and three assistant keelsons, port and starboard. The rider keelson and part of the main keelson (upper portion) are exposed above the top surface of the assistant keelsons and therefore are readily available for stress wave scanning. The assistant keelsons, on the other hand, only have the top face exposed. Therefore the internal condition of the assistant keelsons can only be evaluated through micro-drilling tests.

6.1.1 Rider Keelson and Main Keelson

The rider keelson and main keelson (above the top surface of the assistant keelsons) in the cargo hold were stress wave scanned along three lines (Figure 3a). Line A and B were on the rider keelson and line C was on the main keelson. The portion of the keelsons tested is between frame 7 and 48. The keelsons beyond this portion were not tested due to lack of access or difficulty to access.

Figure 7 illustrated the distribution of stress wave transmission time (SWTT) (unit: µs/ft) along the length as well as the mapping of physical conditions of the rider keelson and main keelson. The physical conditions of each test location were rated into four categories by comparing the measured SWTT with the reference SWTT and color-coded as the following:

🟨 Solid: < 300 µs/ft
🟦 Moderate decay: 300 - 600 µs/ft
🟥 Decay: 600 - 900 µs/ft
🟫 Severe decay: > 900 µs/ft

The deterioration of the keelsons is concentrated between frame 25 and 42 and most severe decay occurred on the main keelson timber between frame 30 and 39. This is also confirmed by resistance micro-drilling tests (Appendix C1). It is likely that rainwater got into this area through the hatch over the years due to failed weather protection and water remained trapped. The water damage in untested portion of the main keelson between frame 30 and 39 and even beyond could also be significant. Deterioration could be further extended and advanced with the current outdated weather protection.

No significant deterioration was found between frame 7 and 25 according to stress wave scanning results. The tween deck, which extends from frame 11 to the forward end of the hatch at frame 26, has apparently protected the keelsons from direct exposure to rainwater dripping from above (through main decking). The Resistograph drill test revealed isolated internal rot (5 ½ - 9 ½ in.) at the location of frame 12. Similar condition at frame 11 was reported in a 1986's survey report (Tri-Coastal Marine, Inc. 1986).

6.1.2 Assistant Keelsons

Assistant keelsons are deteriorated variously in the hold area. Resistance micro-drilling on assistant keelsons at frame 8, 32, and 48 revealed both surface decay and internal decay as shown in Table 1 (Resistograph charts are shown in Appendix C3 – C5). An area of severe deterioration is seen between frames below the hatch.

We also observed that many surface areas of the assistant keelsons are saturated with rainwater, presumably dripping from the main deck, tween deck, or the main hatch. Moisture readings collected at many locations are well above the fiber saturation point (30%), indicating the potential of further deterioration (Moisture content data is shown in Appendix D).

Table 1. Deterioration in assistant keelsons revealed by Resistograph tests.

Frame No.	Starboard		Port	
	1st Assistant keelson	3rd Assistant keelson	1st Assistant keelson	3rd Assistant keelson
8	9 ½ - 11 in. decay	n/a	n/a	n/a
32	0 – 2 ½ in. engraver	9 ½ - 10 ½ in. decay	0 - 3 in. engraver 7 - 8 ½ in. decay	0 – 1 ½ in. decay
48	All solid	0 – 1 ½ in. decay	0 – 5 ½ in. decay	1 – 1 ½ in. decay 7 – 8 ½ in. decay

6.2 Keel

Stress wave scanning and mapping of the keel was done between frame 5 and 79. The scanning pattern is shown in Figure 3b. For the convenience of quickly establishing a scan pattern, we set frame 79 (where the iron tie plate ends) as the starting point and scanning was proceeded along two lines (A and B) from aft to fore. Stress wave transmission time data was collected between the keel blocks and at six feet intervals. Figure 8 shows the distribution of stress wave transmission time (unit: µs/ft) and the mapping of physical conditions of the keel.

Moderate deterioration was found at several areas of the keel as indicated in the mapping. Although no severe decay is present in the keel, the hogging in the mid section of the ship has caused significant mechanical damages (shear failure) to the keel as evidenced by the cracks or splits along the grain. This is also confirmed by previous report that the keel was broken when the ship was placed on the Barge 214 (Tri-Coastal Marine, Inc. 1986).

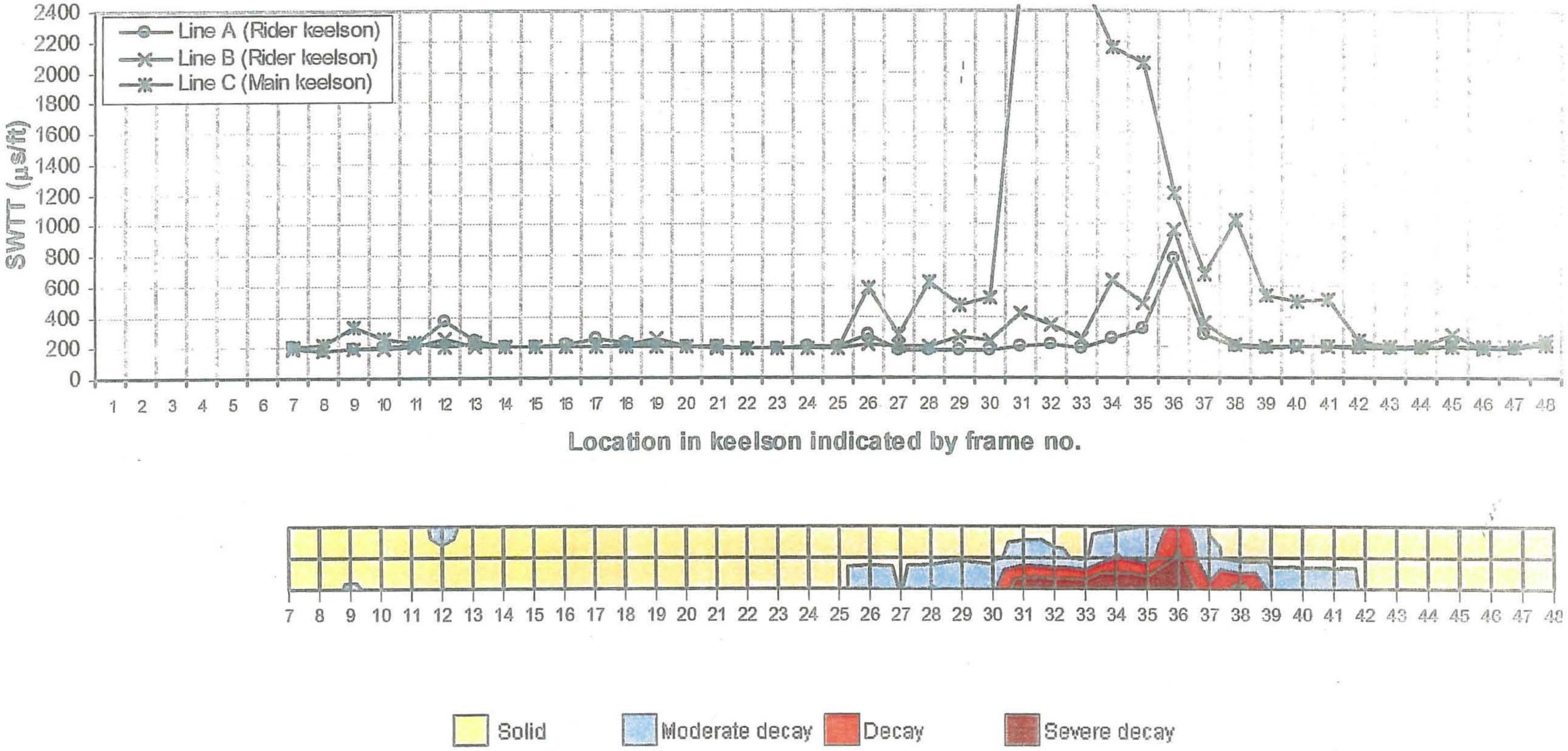


Figure 7. Distribution of stress wave transmission time (SWTT) and mapping of physical conditions of the keelsons.

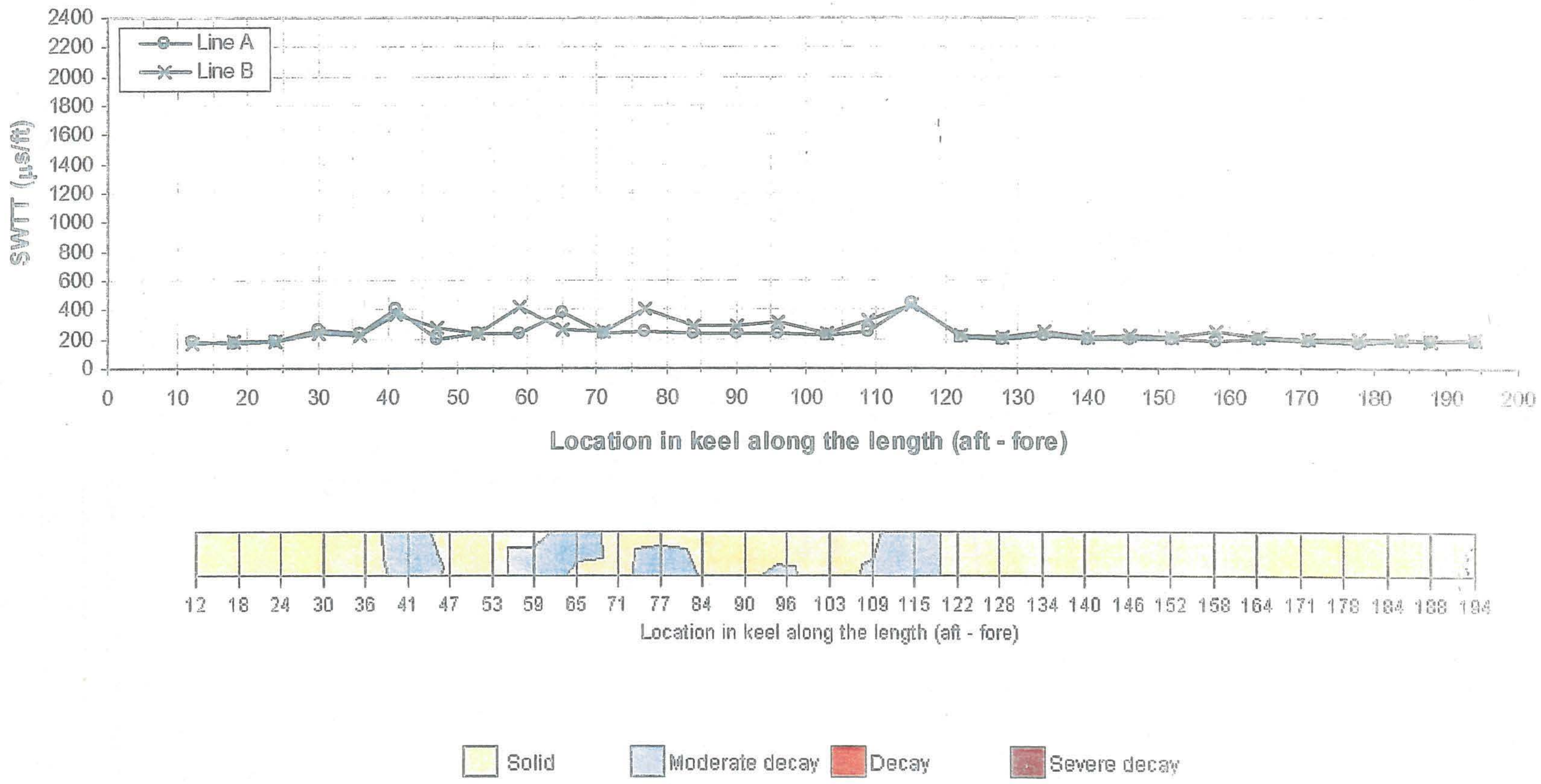


Figure 8. Distribution of stress wave transmission time (SWTT) and mapping of the physical conditions of the keel.

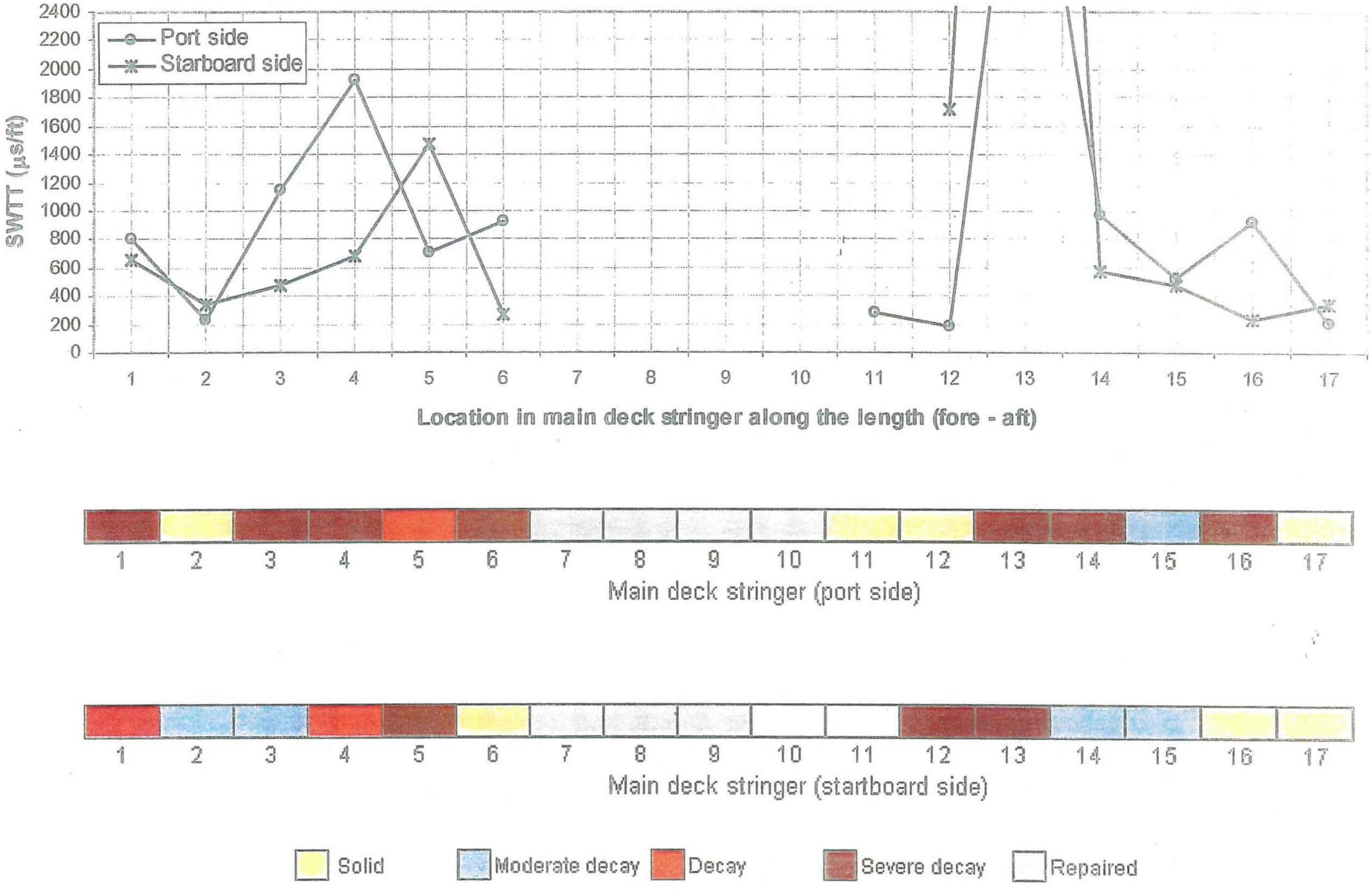


Figure 9. Stress wave transmission time (SWTT) and physical conditions of the main deck stringers.

6.3 Main Deck Stringers

The main deck stringers have lost most integrity due to severe deterioration. Visual signs of rot, splits, and checks are present in most portions of these members. To quantify the levels of deterioration, stress wave scanning was carried out on two side stringers with a less extensive interval (5 ft) and along the centerline of the member.

Figure 9 shows the distribution of stress wave transmission time (unit: µs/ft) along the length as well as the mapping of physical conditions of the main deck stringers.

6.4 Main Framing Timbers

The main framing timbers of the WAPAMA were evaluated through micro-drilling tests at three main cross-sections of the main hull assembly: 1) section at frame 8; 2) section at frame 32; and 3) section at frame 48 (Figure 1). Frame 8 is located in fore section of the cargo hold area near the vessel's bow. Frame 32 is located mid-ship area underneath the main cargo hatch. Frame 48 is located in aft portion of the cargo hold area approximately 3 ft forward of the engine room.

6.4.1 Cross-Section at Hull Frame 8

A total of seven micro-drilling resistance measurements were collected from the hull assembly at frame 8 (Figure 4). Safety concerns limited our access to the smaller area underneath the tween deck, therefore no data was collected from tween deck beams. From the interior of the vessel, five micro-drilling locations penetrated downward through ceiling planks and a portion of the hull frame. One additional micro-drilling location penetrated into the first assistant keelson (starboard). From the exterior of the vessel, one micro drilling location on the starboard side penetrated upward through strake planks and a portion of the hull frame. The thickness of the interior ceiling and/or exterior strake planking varied and resulted in differing penetration levels into the main frame members.

A schematic summary of micro-drilling resistance data collected at hull frame 8 is provided in Figure 10 (micro-drilling plots for hull frame 8 are provided in Appendix C3). Severe decay was detected at two out of seven (29%) drilling locations at this section. Most of the ceiling planks and the first assistance keelson (starboard) are in good condition, with decay present only in the ceiling plank at drill location no. 2. Moderate decay was detected in the inside upper portions of the hull frame drill locations, with severe decay present at drill location no. 2. There were visual indicators of water seepage through overhead tween and main decks that probably caused this deterioration since the WAPAMA was lifted onto barge 214.

6.4.2 Cross-Section at Hull Frame 32

A total of forty micro-drilling resistance measurements were collected from the hull assembly at frame 32 (Figure 5). Eighteen micro-drilling locations were from the interior portion of the hull assembly and penetrated into clamps, ceiling planks, and assistant keelson members. Fourteen micro-drilling locations were from topside of the main deck and penetrated into bulwarks, waterways, decking, stringers, and assistance stringers.

Eight micro-drilling locations were from the outer hull portions that were accessible from the barge deck.

A schematic summary of micro-drilling resistance data collected at hull frame 32 is provided in Figure 11 (micro-drilling plots for full frame 32 are provided in Appendix C4). Severe decay was detected at fifteen (38%) of all drilling locations with most of these areas located in the members at the main deck level (stringers and main deck beams) or near the main deck level (clamps, hull frame). The deterioration of the lower hull members and keelsons was mostly moderate. Deterioration ranging from decay to severe decay was detected at nearly all drilling locations drilled downward from topside main deck. The outer waterways 19 and 30 and portside main deck planks (21 and 22) showed signs of moderate decay. Deterioration ranging from decay to severe decay was detected in clamps 1, 2, and 17, ceiling planks 5, 12, and 14, the 3rd assistant keelson portside 11), and the inside upper portion of the hull frame 1, 3, 5, 14, and 17. Drillings upward into the outer hull detected mostly sound wood with only moderate decay present in the outer lower hull frame B.

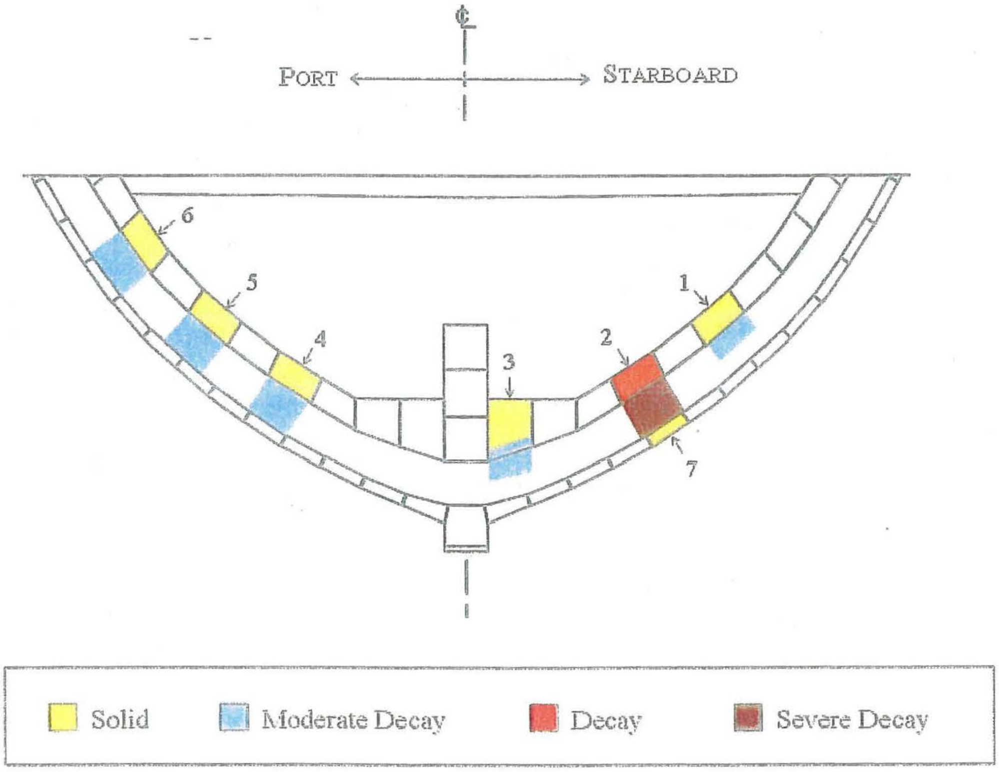


Figure 10. Mapping of physical conditions of the cross-section at frame 8 (Resistograph interpretation).

6.4.3 Cross-Section at Hull Frame 48

A total of forty micro-drilling resistance measurements were collected from the hull assembly at frame 48 (Figure 6). Eighteen micro-drilling locations were from the interior portion of the hull assembly and penetrated into clamps, ceiling planks, and assistant

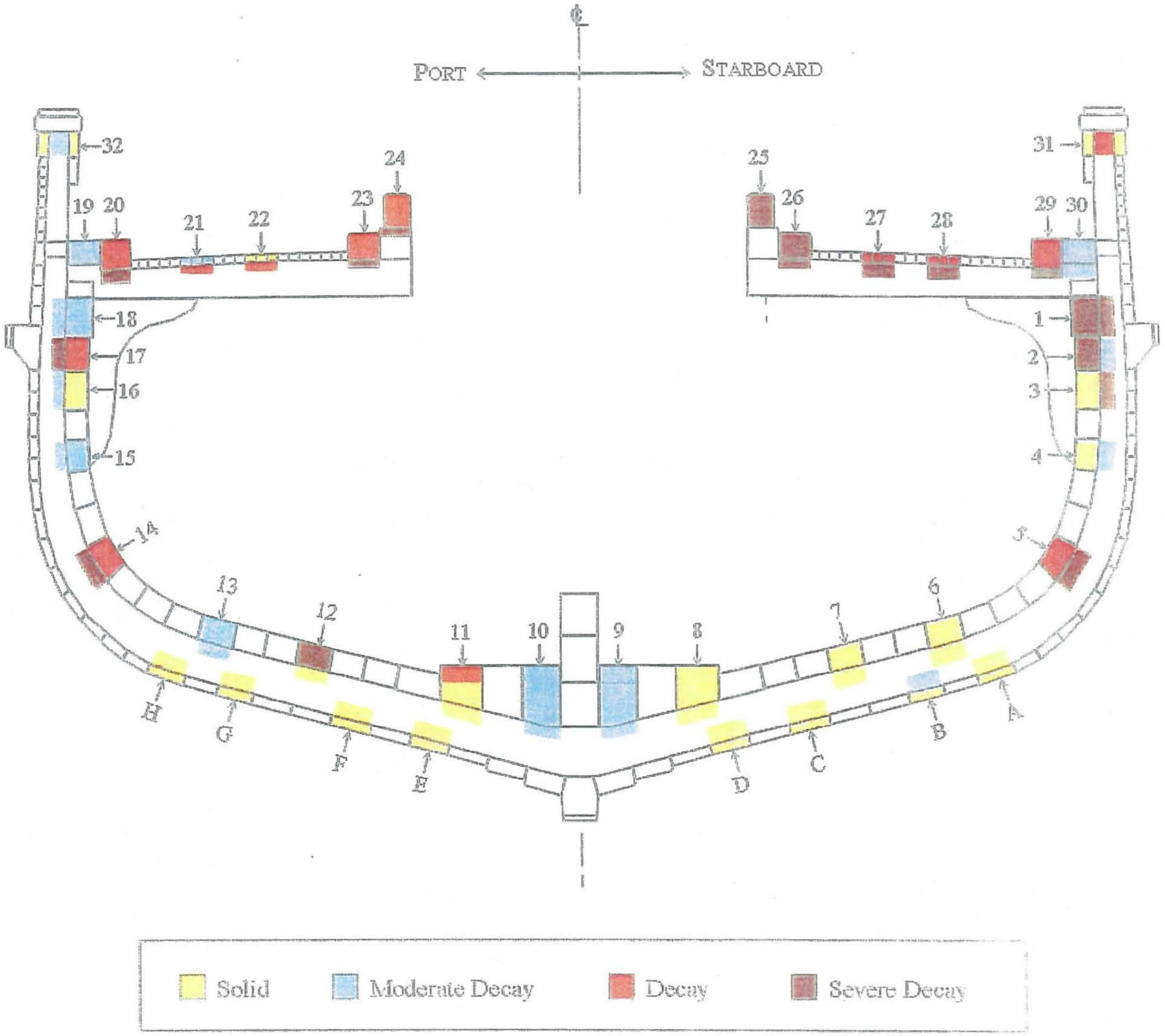


Figure 11. Mapping of physical conditions of the cross-section at frame 32 (Resistograph interpretation).

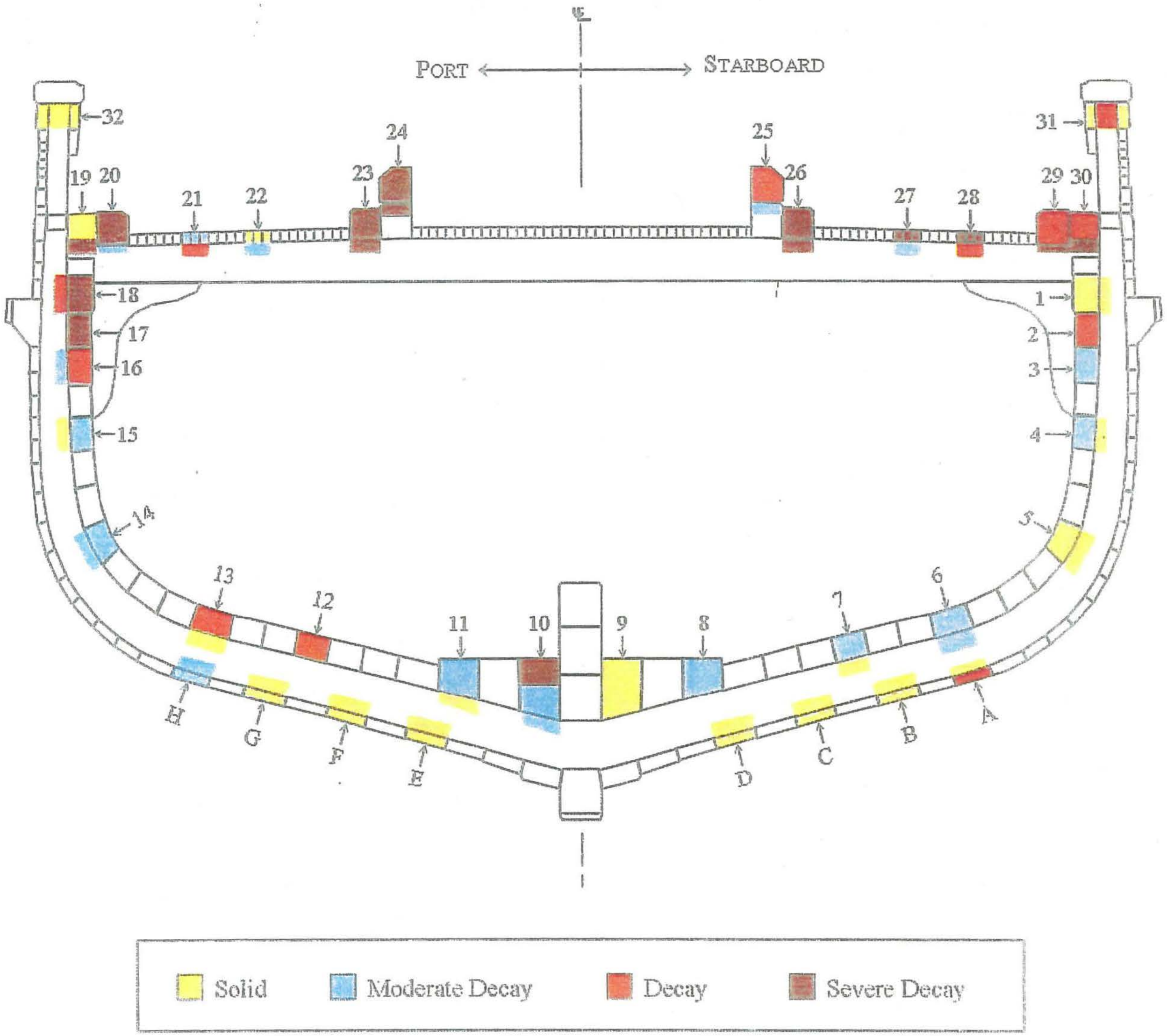


Figure 12. Mapping of physical conditions of the cross-section at frame 48 (Resistograph interpretation).

keelson members. Fourteen micro-drilling locations were from topside of the main deck and penetrated into bulwarks, waterways, decking, stringers, and assistance stringers. Eight micro-drilling locations were from the outer hull portions that were accessible from the barge deck.

A schematic summary of micro-drilling resistance data collected at hull frame 48 is provided in Figure 12 (micro-drilling plots for hull frame 48 are provided in Appendix C5). Severe decay was detected at twelve (30%) of all drilling locations with most of these areas located in the members at the main deck level (waterways, stringers, main deck planks, and main deck beams) or near the main deck level (clamps). The deterioration of the lower hull members and keelsons was mostly moderate. Deterioration ranging from decay to severe decay was detected at nearly all drilling locations drilled downward from topside main deck, except main deck plank 22. Deterioration ranging from decay to severe decay was also detected in clamps 2, 16, 17, and 18, the 1st assistant keelson portside (10), ceiling planks 12 and 13, and the inside upper portion of the hull frame 18. Drillings upward into the outer hull detected mostly sound wood with deterioration noted only in outer hull plank A and in outer hull plank/hull frame H.

6.5 Main Deck Beams

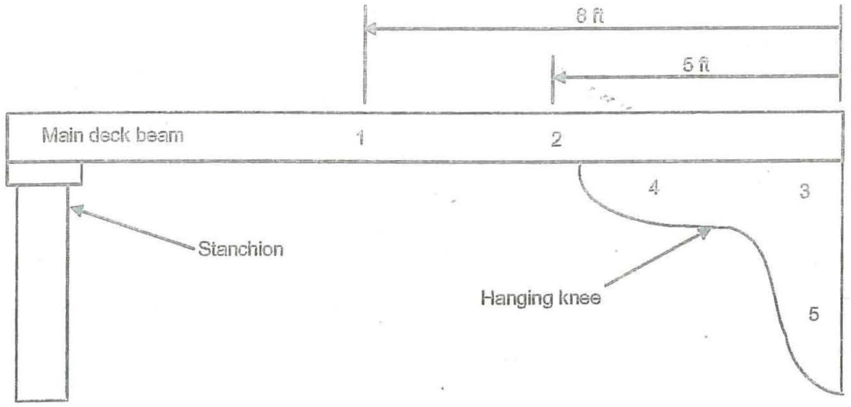
Stress wave transmission data was collected from the main deck beams at two areas on the ship's portside (Figure 13). Five test locations were located in the main deck beams above the tween deck including some at the hanging knees (Figure 13a). Five test locations were also located in the rear cargo hold between the main hatch and the cabin deck (Figure 13b). A summary of the condition of the main deck beams is provided in Table 2 and Figure 14.

6.5.1 Beams above Tween Deck

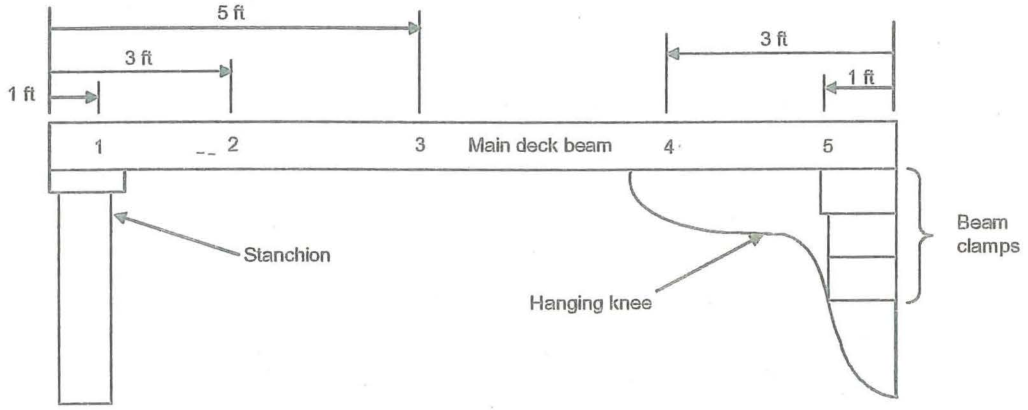
Stress wave transmission data confirmed that the main deck beams above the tween deck are in an advanced state of deterioration. Decay and severe decay were detected at all beams as indicated by the stress wave transmission times in Table 2. Beams located at or near hull frames 13, 15, 20, 22, 24, and 26 have almost lost their entire strength and are considered having zero load capacity. In addition, severe deterioration was found in the hanging knees at frames 15 and 26, which raise serious concerns on the rest of the hanging knees that have not been tested.

6.5.2 Beams at Rear Cargo Hold

The condition of the main deck beams at rear cargo hold varied. Decay to severe decay is present at the beam ends over the stanchion for most beams. The exception is the deck beam located near hull frame 44 which is sound. At the beam ends near the outer hull frame, only the beam at hull frame 40 shows decay, the beams near frames 38 and 46 shows moderate decay and the beams near 42, 44, and 48 are generally sound. The condition of the main deck beams away from their supports is mostly sound with moderate deterioration detected at some beams. The main deck beam in the best condition is at hull frame 44. Severe deterioration was present only at the end support (over the stanchion) at hull frame 42.



(a) Main deck beams and hanging knees above tween deck



(b) Main deck beams at rear cargo hold

Figure 13. Stress wave testing locations for portside main deck beams.

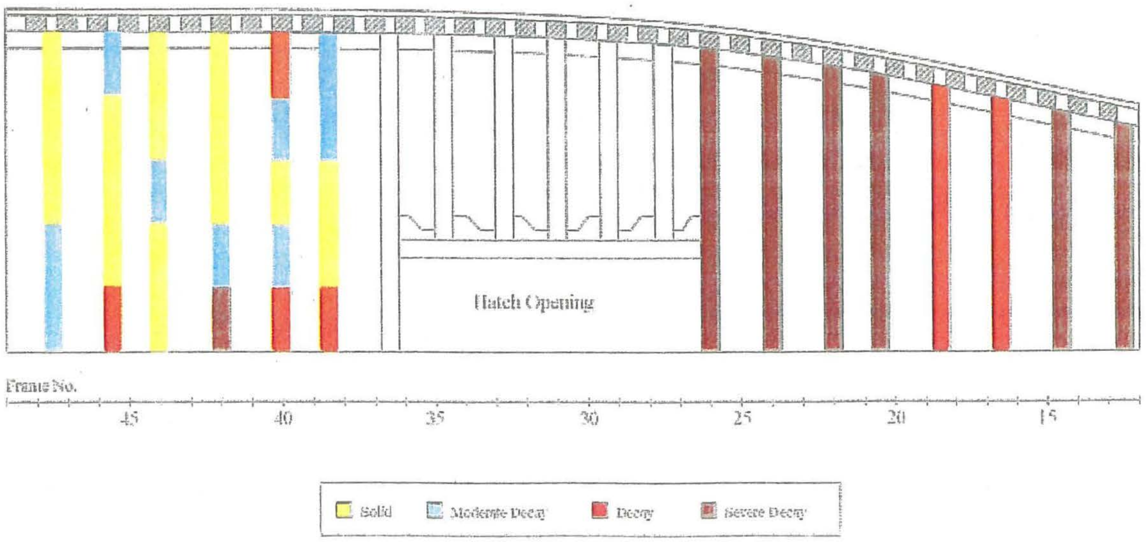


Figure 14. Mapping of physical conditions of portside main deck beams (Plan view).

Table 2. Stress wave transmission time (SWTT) and physical conditions of the portside main deck beams and hanging knees.

Portside beam location	Ref. frame no.	Relative Deterioration Level and SWTT (µs/ft)				
		Main deck beams			Hanging knees	
		1	2	3	4	5
Above tween deck	26	Severe 1051	Moderate 397	Severe 4948	Severe 2966	Severe 3050
	24	Decay 700	Severe 828	--	--	--
	22	Severe 3087	Severe 4374	--	--	--
	20.5	Severe 1551	Severe 3126	--	--	--
	18.5	Decay 759	Moderate 568	--	--	--
	16.5	Moderate 555	Decay 742	Decay 621	Severe 933	Severe 999
	14.5	Severe 4783	Severe 4997	--	--	--
	12.5	Severe 4966	Severe 5379	--	--	--
		Main deck beams				
		1	2	3	4	5
Rear cargo hold	38.5	Decay 736	Sound 221	Sound 225	Moderate 575	Moderate 378
	40	Decay 678	Moderate 442	Sound 206	Moderate 474	Decay 698
	42	Severe 969	Moderate 329	Sound 187	Sound 230	Sound 190
	44	Sound 177	Sound 207	Moderate 427	Sound 282	Sound 209
	45.5	Decay 628	Sound 254	Sound 222	Sound 249	Moderate 486
	47.5	Moderate 429	Moderate 529	Sound 204	Sound 296	Sound 292

6.6 Vertical Supporting Columns

The physical conditions of six pillars and twenty hold stanchions were evaluated with stress wave transmission technique. The pillars were located in the aft part of the ship with their length spanning the hold to the boat deck. The hold stanchions are located in the hold of the ship and support the main deck beams. Member testing was took place in two directions – the fore-to-aft direction, where the test faces were to the forward and aft of the ship, and port-to-starboard, where the test faces were to the port and starboard directions of the ship, respectively.

6.6.1 Pillars

The pillars were tested at three levels of the ship: engine/boiler room (lower level), main deck (middle level), and cabin deck (upper level). The lower level of the ship allowed access to fore-to-aft and port-to-starboard faces on all six pillars (A-F, Figure 15), whereas the main deck only allowed access to four pillars, those in the forward part of the cabin deck house (A-D), and in the fore-to-aft direction. The pillars accessible on the upper level (cabin deck house) were the two in the foremost part of the engine room (A and B), and they were only accessible in the port-to-starboard direction. Table 3 summarizes the physical conditions of the pillars evaluated by stress wave tests (the stress wave transmission data of the pillars is shown in Appendix B7).

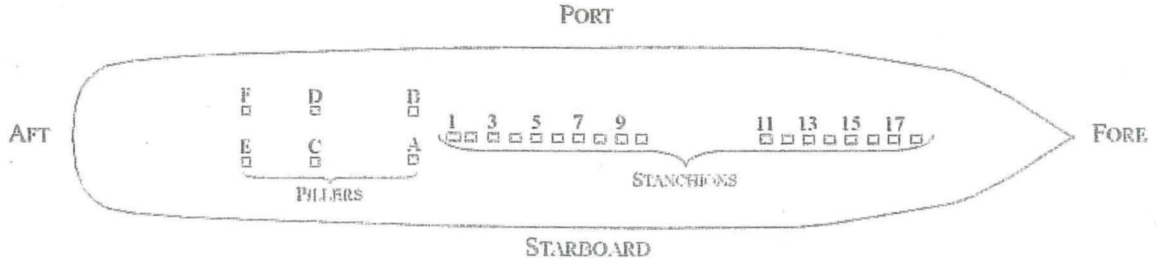


Figure 15. Location of pillars and stanchions on the ship (Plan view).

Table 3. Physical conditions of the pillars evaluated by stress wave tests.

Pillar	Deck Level		
	Lower	Middle	Upper
A	Moderate	Decay	Solid
B	Moderate	Decay	Solid
C	Decay	Moderate	Not accessible
D	Moderate	Solid	Not accessible
E	Solid	Not accessible	Not accessible
F	Solid	Not accessible	Not accessible

Deterioration is present in most pillars, but varies at different levels (lower, middle, and upper). Pillars A and B show moderate deterioration in the lower level, decay in the middle level, and are sound in the upper level. Pillars C and D have areas of moderate deterioration and decay in the lower and/or middle level, while pillars E. and F are found in sound condition in the lower level. Since the pillars E and F could only be accessed and tested at one level of the ship, the testing results are not conclusive for the entire members.

6.6.2 Hold Stanchions

The hold stanchions were first visually assessed for deterioration, then a subset of the members was spot-checked with stress wave transmission testing. The hold stanchions tested were numbers 1-3, 5, 7-10, 13-15, 17, and 20 (Figure 15). Hold stanchions 1, 2, and 3 were found to have moderate decay, with stress wave transmission times ranging from 326 to 584 µs/ft. The remaining hold stanchions were found to be solid with stress wave transmission times ranging from 179 to 200 µs/ft.

6.7 Pointers

The pointers tested were the second pointers in the front of the ship accessible by the tween deck in the hold. There is one pointer on each side of the boat and they were labeled as the port and starboard pointers. The pointers were spot-checked with stress waves at 4-ft. intervals beginning at the foremost part of the member. Results show that the pointers are generally in a sound condition. The aftmost 4 feet on the portside pointer and the aftmost 8 feet on the starboard pointer had a large crack that resulted in moderate levels of deterioration, but the remaining length of each member was solid. Stress wave transmission times ranged from 190 to 287 µs/ft in solid areas and from 460 to 518 µs/ft in moderately decayed areas.

7. Summary

A general condition assessment of the historic steam-schooner, WAPAMA, was conducted during a four-day period in January 2006. Our investigation focused on the key structural components that provide the structural integrity of the vessel. Structural components tested that provide for longitudinal integrity are the keelsons (rider keelson, main keelson, and assistant keelsons), main deck stringers, waterways, bulwarks, and keel. Structural components tested that provide for transverse integrity are the hull assembly (framing timbers, ceiling, clamps, strakes) at three cross-sections and the main deck beams. Due to limited inspection time, the investigation was not intensively focused on individual members, but instead was conducted with relatively large scan intervals or through spot-checking of suspected areas. Stress-wave timing and resistance micro-drilling were the primary methods used in this investigation, coupled with visual inspection and moisture content determination.

7.1 Condition of Structural Components

7.1.1 Keelsons

The rider keelson and main keelson (top-tier) were evaluated between frame 7 through 48 with stress wave scanning and resistance micro-drilling. Advanced deterioration of the keelsons was concentrated under the main hatch area. The rider keelson was deteriorated between frame 30 through 39, and the main keelson (top tier) was deteriorated between frame 25 through 42. No significant deterioration was detected in the keelsons under the tween deck between frame 7 and 25. Assistant keelsons were evaluated with resistance micro-drilling (topside downward) at frames 8, 32, and 48. Resistance plots indicated only isolated pockets of moderate decay.

7.1.2 Main Deck Stringers

The main deck stringers were spot-checked with stress-wave timing and resistance micro-drilling. Severe deterioration was confirmed in both side stringers and assistant stringers. Overall, the main deck stringers have lost nearly all structural integrity.

7.1.3 Waterways and Bulwarks

Waterways and bulwarks were evaluated at several locations with resistance micro-drilling at the main deck. Most severe deterioration was present in the waterways, while many of the bulwarks had moderate to severe decay.

7.1.4 Keel

The keel was evaluated at 6 ft intervals (between the keel blocks) with stress-wave timing and spot-checked with resistance micro-drilling. Moderate deterioration was present at several locations in aft half of the keel. Visual signs of large splits and cracks may indicate that the keel was broken while being lifted onto barge 214.

7.1.5 Hull Assembly

The hull assembly was evaluated at frames 8, 32, and 48 using resistance micro-drilling techniques. The condition of the hull assembly at frame 8 is generally good, with moderate decay present in the ceiling and framing timbers. Severe deterioration was confirmed at one location near the assistant keelson with both inboard and outboard drilling data. The condition of the lower hull assemblies at frame 32 and 48 is good with minor pockets of decay present at a few locations. All clamps and upper framing timbers at frames 32 and 48 have moderate to severe decay present.

7.1.6 Main Deck Beams

The main deck beams at the portside of the vessel were spot-checked with stress wave timing. Severe deterioration was found present in nearly all main deck beams above the tween deck. Test results indicate that these beams have lost entire structural integrity and have potential to collapse in the near future, which poses a significant safety hazard. The main deck beams at the rear cargo hold area are mostly sound, with moderate to severe decay found at the end support areas.

7.2 Condition of the Vessel by Areas

7.2.1 Area Under Cabin Decks

Findings for the aft portion of the vessel beneath the cabin decks were largely based on visual assessment. These areas appeared to be generally in good condition as they were similarly reported in the 1986 condition assessment (Tri-Coastal Marine, Inc. 1986).

7.2.2 Main Cargo Hold to Tween Deck

Findings for the midship portion of the vessel extending from the cabin deck to forward hatch side were largely based upon NDE techniques. Significant areas of decay were noted in the following longitudinal structural components: the portion of the rider and main keelson under the main hatch, main deck stringers, and waterways. Significant areas of decay were noted in the following transverse structural components: clamps and framing timbers near waterways, main deck beams, and main deck planking. The lower hull assembly at frames 32 and 48 showed isolated pockets of significant decay.

7.2.3. Tween Deck Forward

Findings for the forward portion of the vessel from the main hatch forward were largely based upon NDE techniques. Significant areas of decay were noted in main deck stringers, waterways, bulwarks, and main deck beams. The main deck beams located over the tween deck are in bad condition with severe internal decay. The lower hull assembly at frame 8 showed an isolated pocket of severe decay.

8. Recommendations

The following recommendations are provided based upon our findings from this on-site investigation:

Repair or replacement of the temporary roof shelter over the main deck is recommended. The current weather protection over the main deck is clearly ineffective in preventing rainwater as evidenced by water seepage from the underside vents in the outer hull. Moisture is saturating several key structural components on the main deck and in the cargo hold. An effective roof will prevent further decay until restoration work is initiated.

Should the decision be made to disassemble the WAPAMA, more intensive NDE scanning and analysis of key structural components is recommended during the restoration process. This will provide more accurate assessment of the extent of internal deterioration and can help in making decisions to retain key components or to salvage portions of key components for non-structural members elsewhere in the restored vessel.

Acknowledgements

We greatly appreciate the effort of Steve Schmieding, Photograph Specialist at the USDA Forest Products Laboratory, for documenting the condition of the WAPAMA and assisting the inspection process during this on-site investigation.

References

BMT Designers & Planners, Inc. 2005. WAPAMA Condition Survey. D&P Report No. 2526-001. Prepared for Architectural Resources Group, Pier 9, The Embarcadero, San Francisco, CA.

Tri-Coastal Marine, Inc. 1986. Steam Schooner WAPAMA – Historic Structure Report. Prepared for The National Maritime Museum at San Francisco, the National Park Service, San Francisco, CA.

Forest Products Laboratory. 2000. Stress wave timing nondestructive evaluation tools for inspecting historic structures - A guide for use and interpretation. Gen. Tech. Rep. FPL-GTR-119. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 15p.

Appendix A. Photographs of the WAPAMA.

Appendix B. Stress Wave Data Summary.

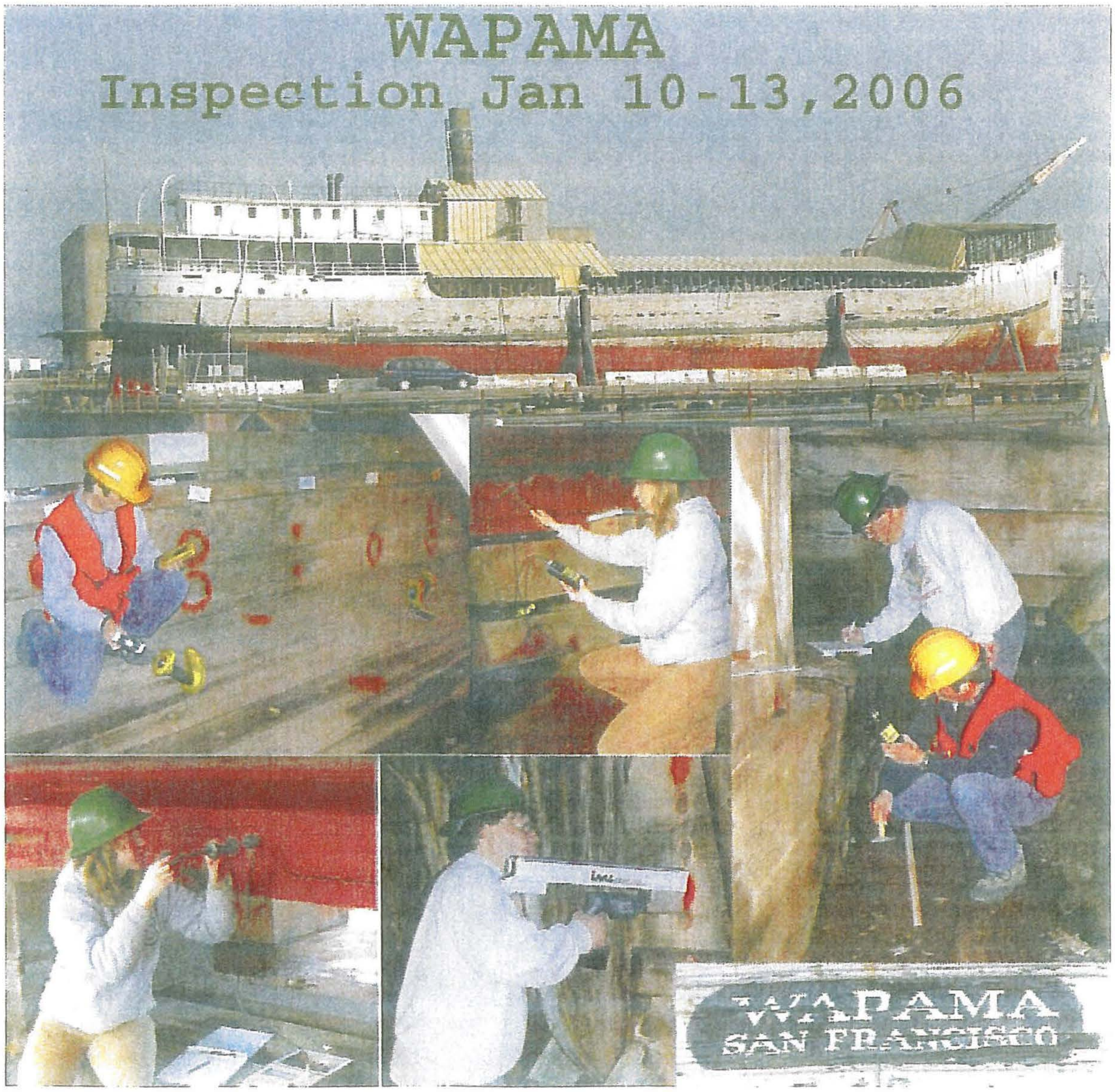
Appendix C. Resistance Micro-Drilling Plots.

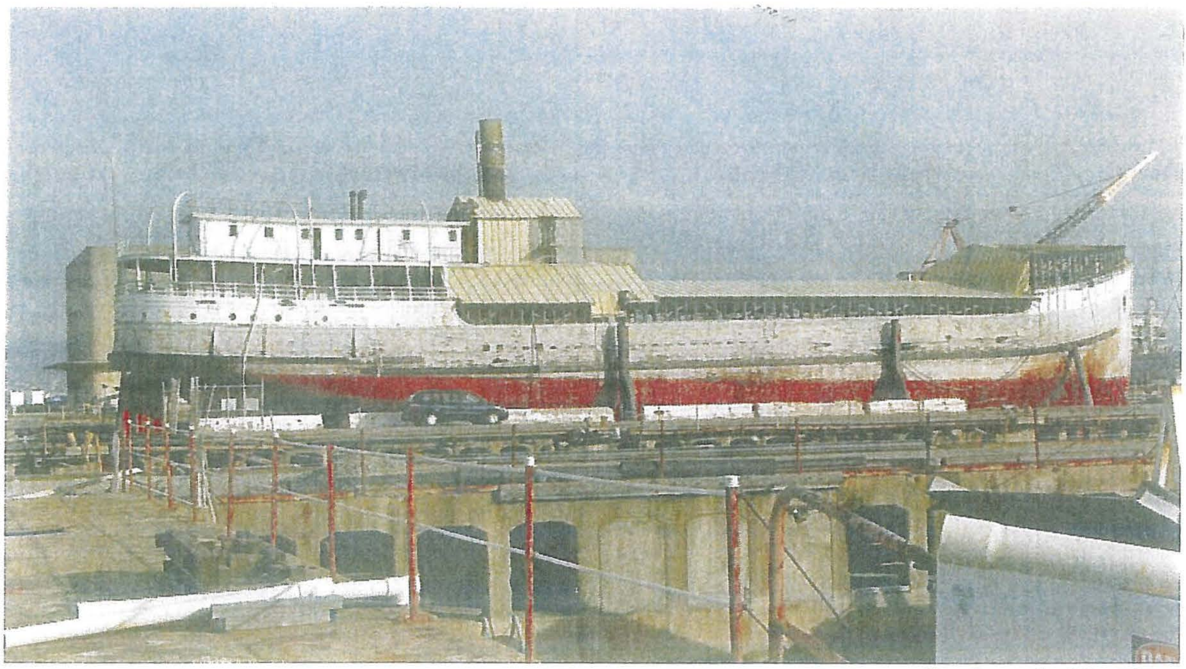
Appendix D. Moisture Content Data Summary.

Appendix E. Stress Wave Timing Nondestructive Evaluation Tools for Inspecting Historic Structures – A Guide for Use and Interpretation.

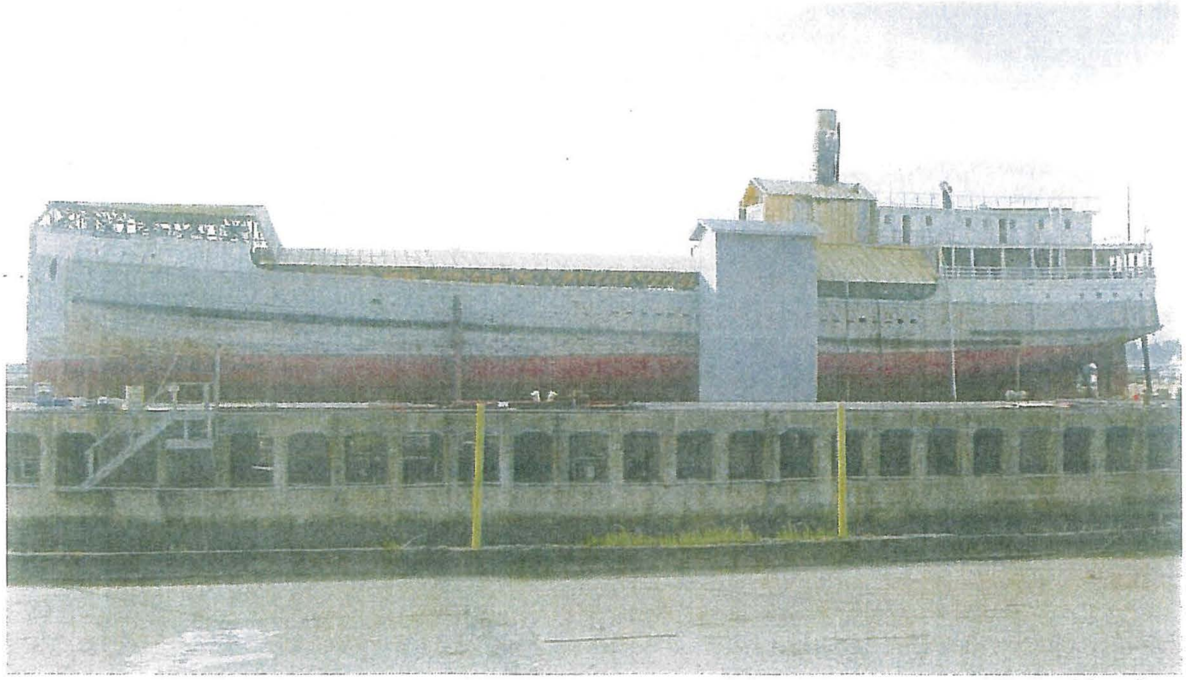
Appendix A

Photographic Documentation

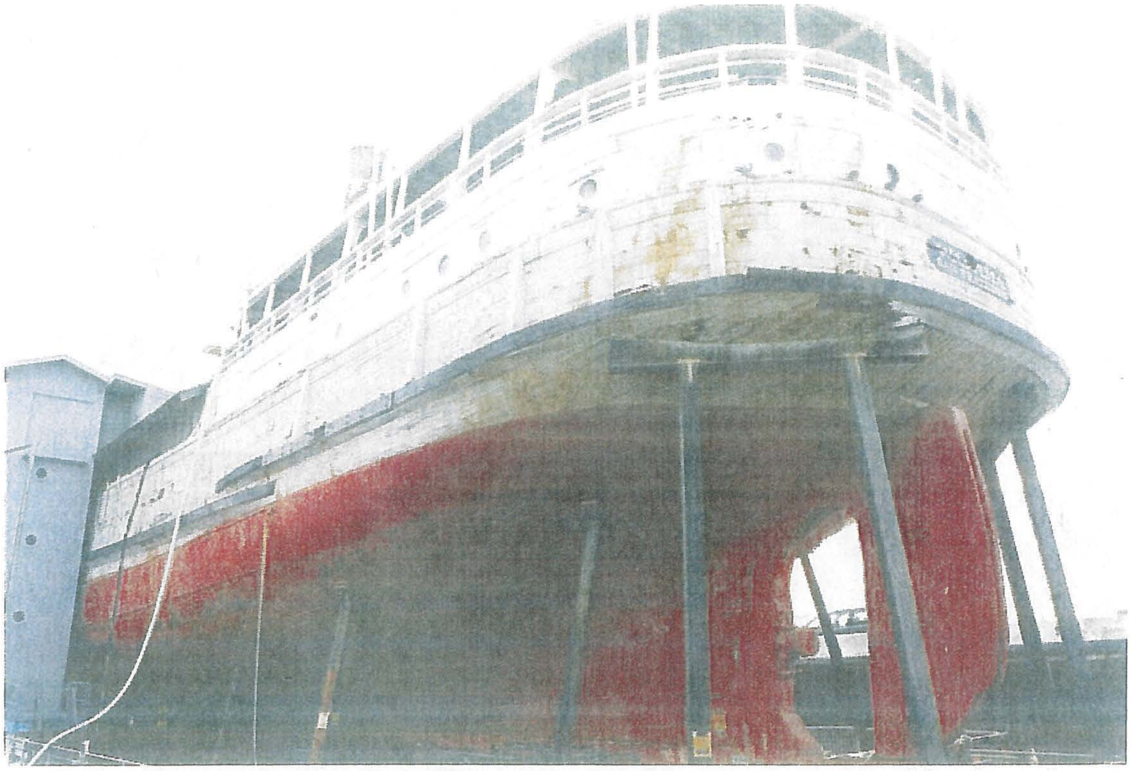




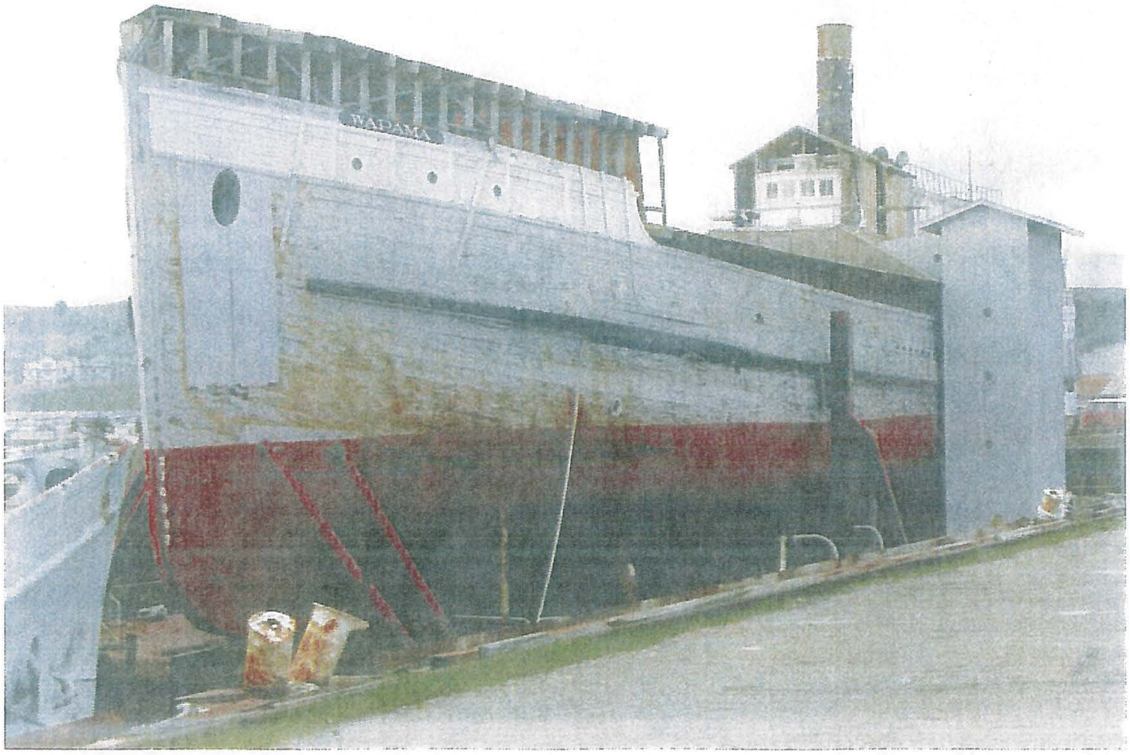
Starboard side view



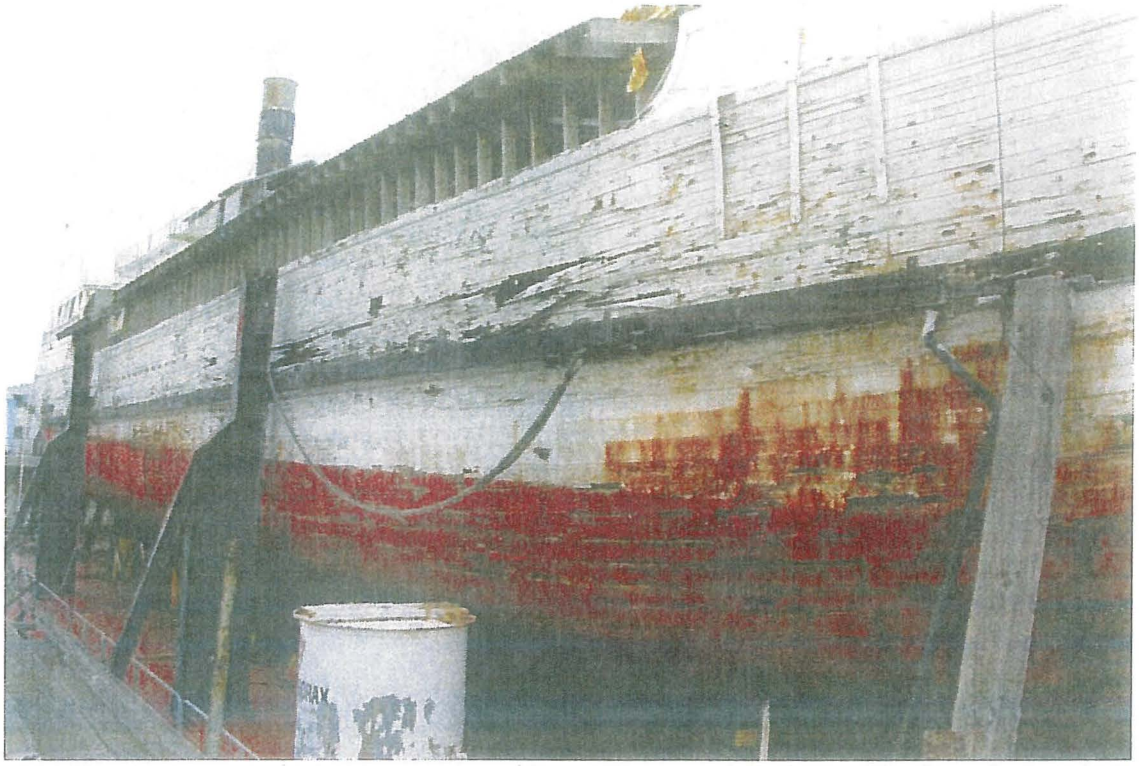
Port side view



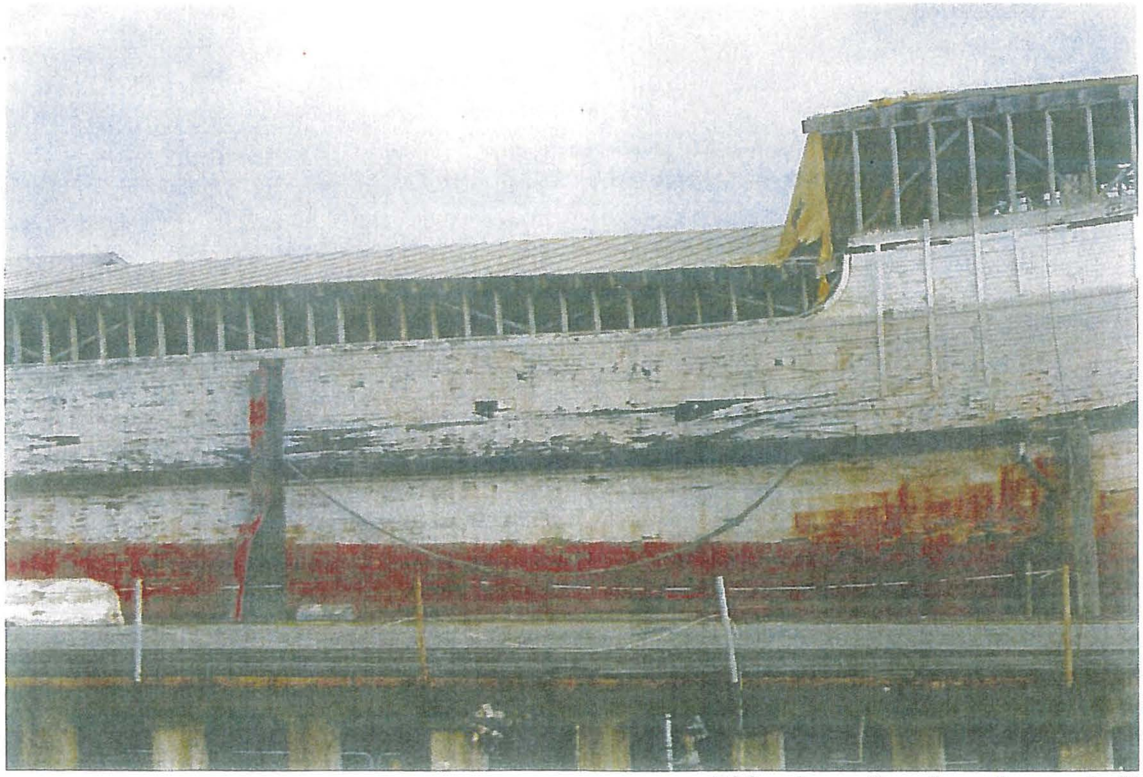
Port side view of stern



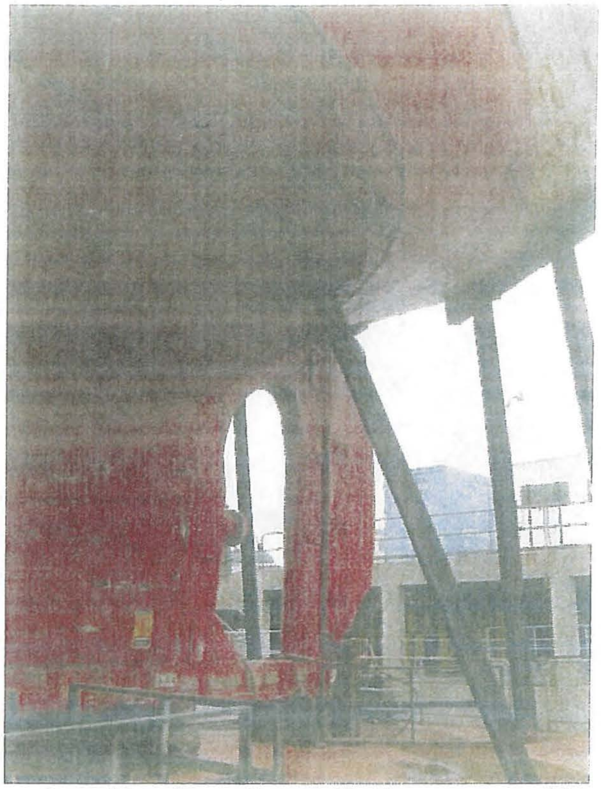
Port side view of bow section



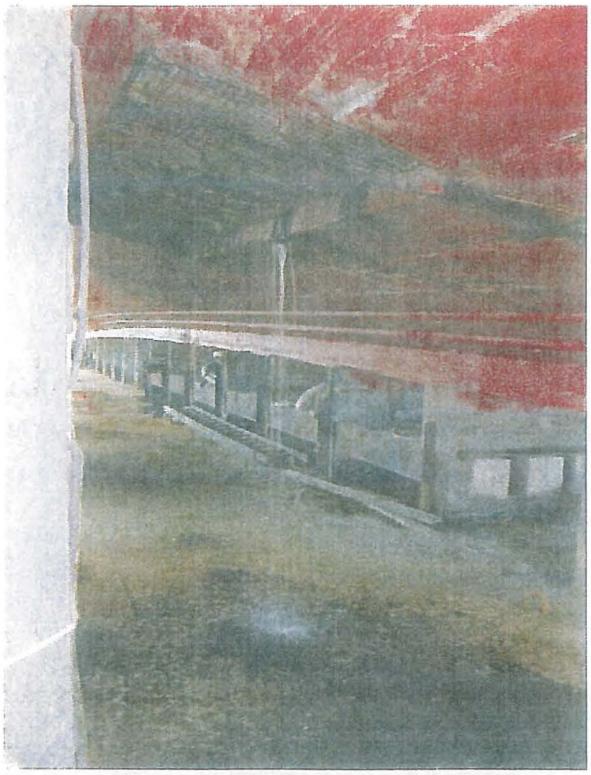
Aft view of starboard outer hull



Side view of starboard outer hull

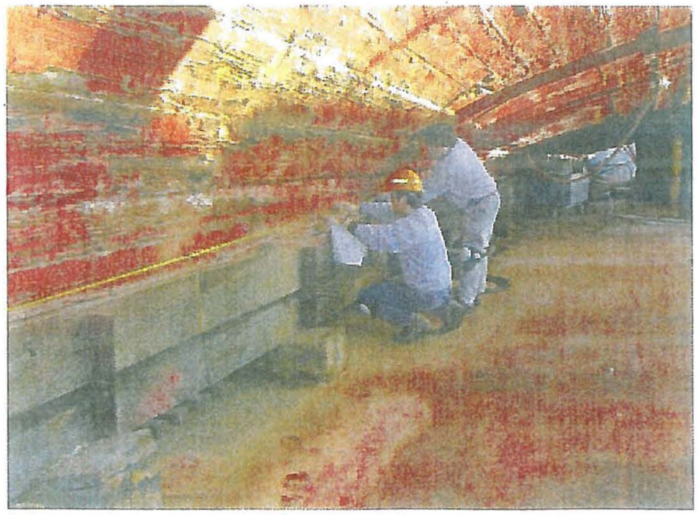


Portside view of propeller/rutter assembly

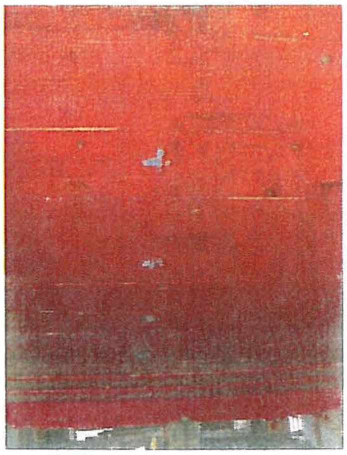


Hull planks removed to vent cargo hold
(note rainwater seepage)

Fore view of keel and hull bottomside

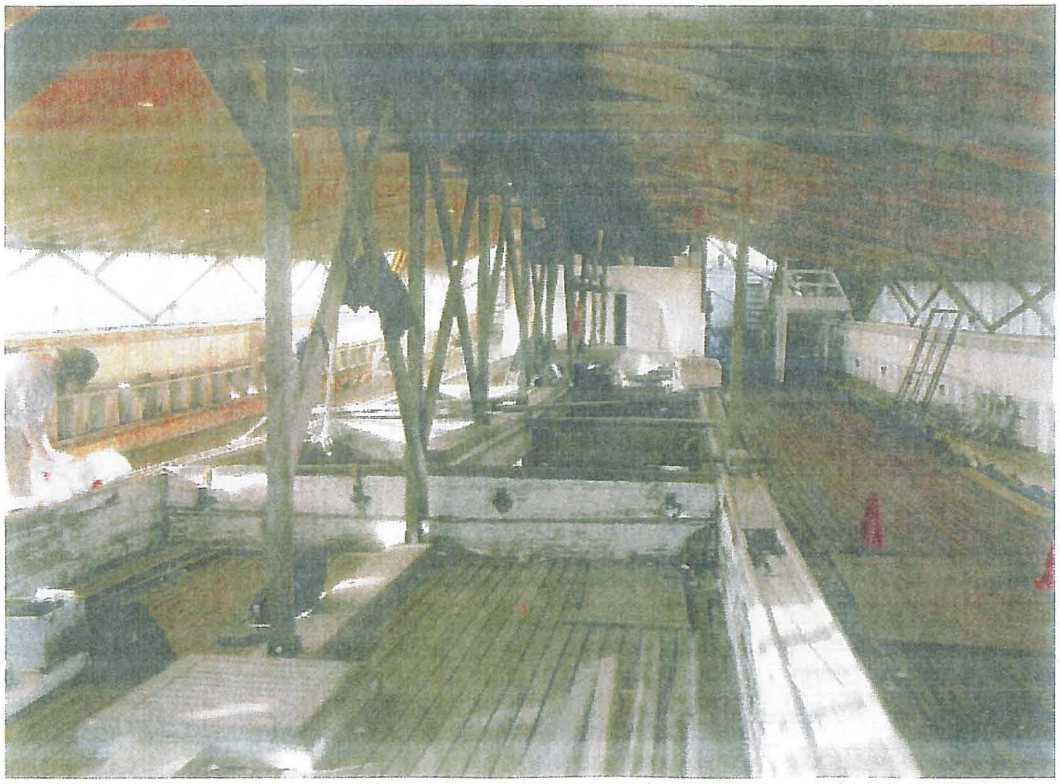


Measuring and marking keel for test locations

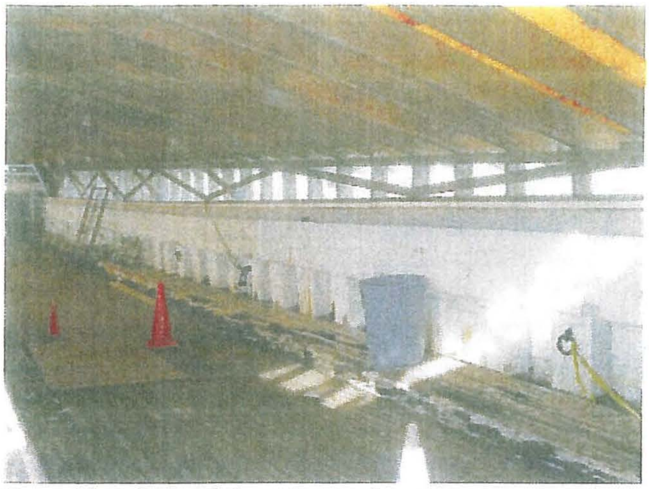


Drill locations at outer hull

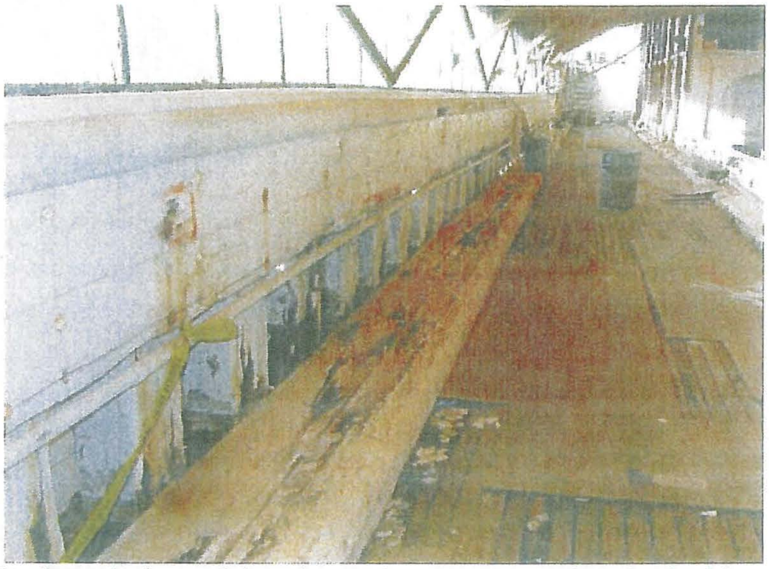
Aft view of tool shop located on main deck



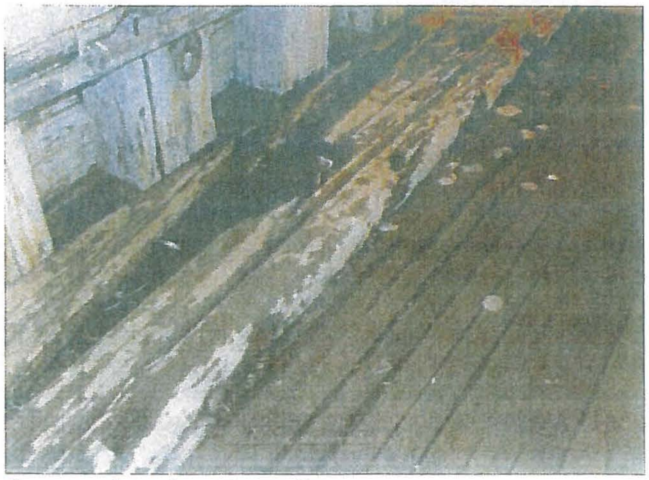
Aft view of main deck area showing main cargo hatch and overhead roof shelter



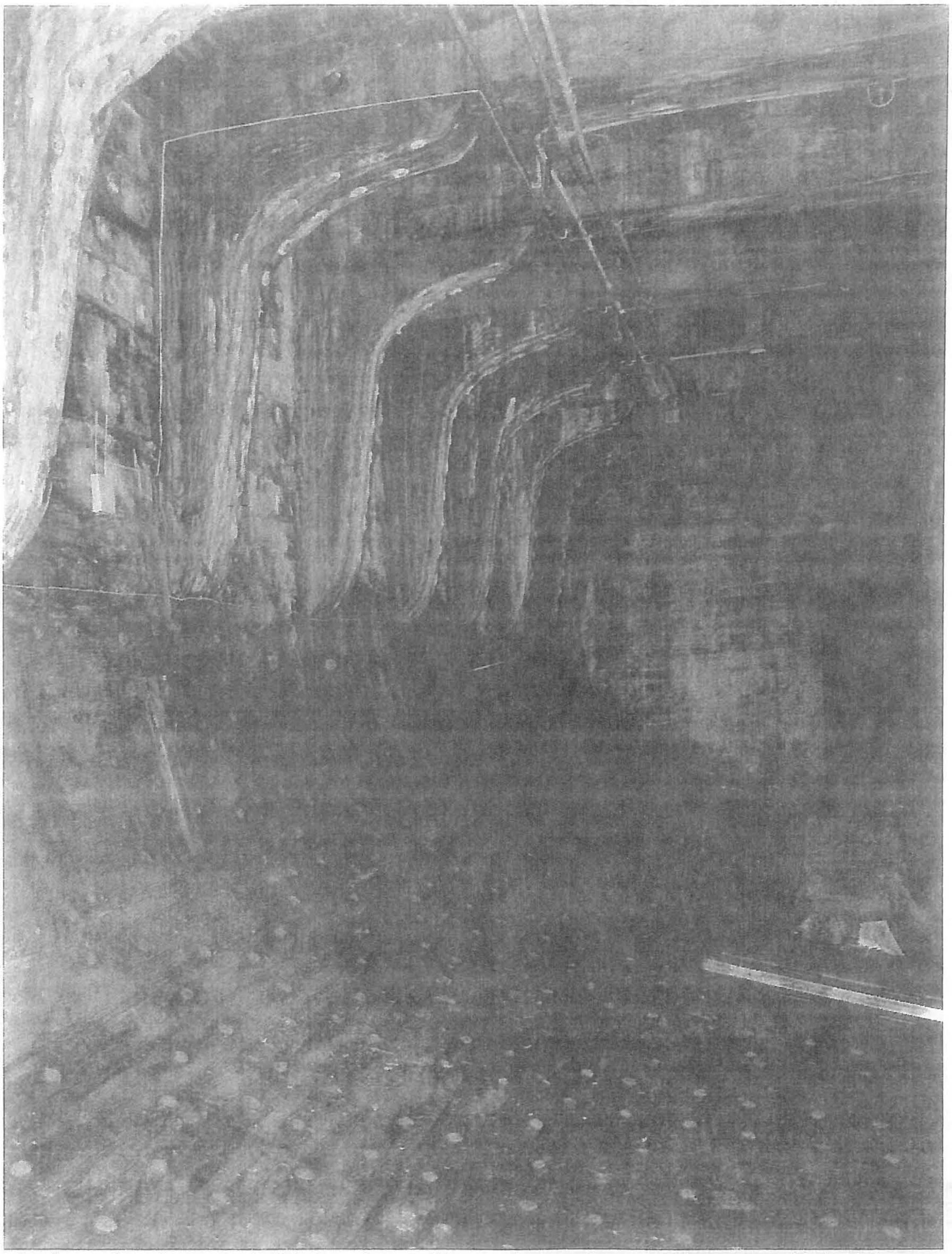
Portside view of deteriorated waterway members



Starboard view of deteriorated waterway and main decking

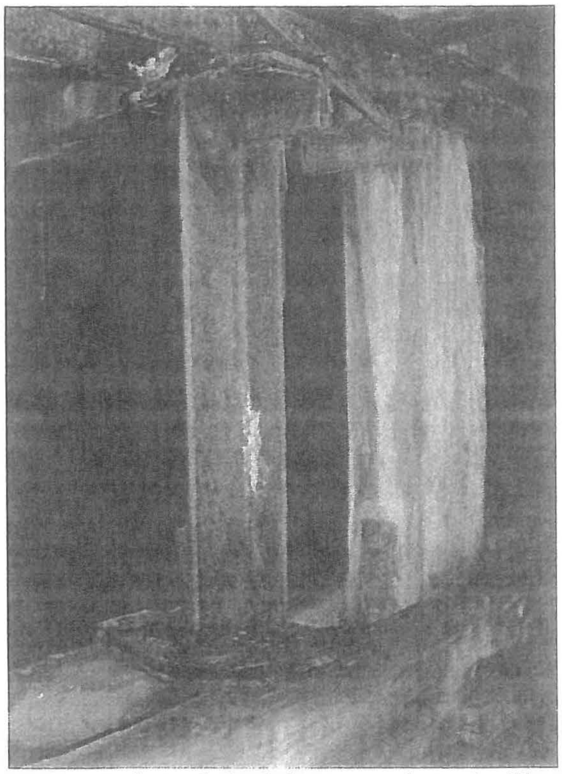


Severe deterioration of waterways



Aft view of main cargo hold showing ceilings, clamps, hanging knees, main deck beams

Evidence of rainwater seepage in keelsons and assistant keelsons near frame 8

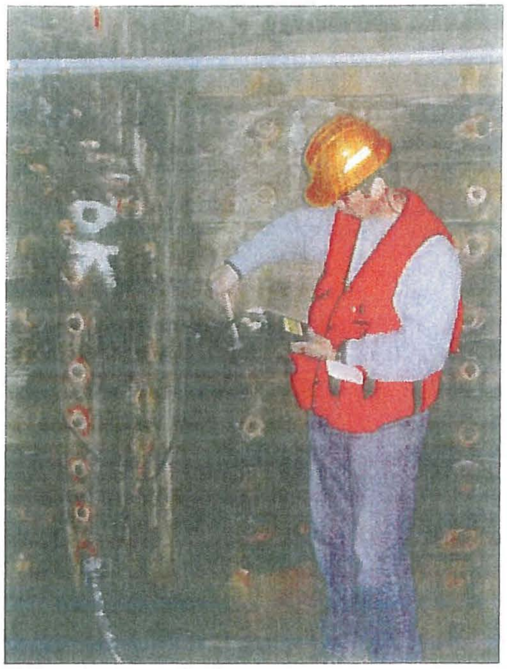


Wasted steel deck beam and steel pillar

Stress wave timing measurements at portside hanging knees over tween deck

Overhead view main cargo hold from main deck

Stress wave timing measurements at main deck beam



Stress wave timing measurements at hanging knee

Stress wave timing measurements at pointer inside the bow.

Resistance micro-drilling a clamp member

Resistance micro-drilling downward into main decking and main deck beam

On-site meeting to identify test locations with members of historic preservation team

Appendix B

Stress Wave Data Summary

B1. Keelsons

B2. Keel

B3. Main Deck Beams above Tween Deck (Portside)

B4. Main Deck Beams at Rear Cargo Hold (Portside)

B5. Main Deck Stringers

B6. Pointers

B7. Pillars

B8. Hold Stanchions

Appendix B1. Keelsons

Dimension: 20 x 17 ½ in.
Test Interval: 2 ft 6 in.
Date: Jan. 10, 2006

Location (Frame No.)	Rider Keelson										Main keelson					Note
	Line A					Line B					Line C					
	Stress wave time (µs/ft)				Velocity	Stress wave time (µs/ft)				Velocity	Stress wave time (µs/ft)				Velocity	
	1	2	3	Avg.	(µs/ft)	1	2	3	Avg.	(µs/ft)	1	2	3	Avg.	(µs/ft)	
1 - 6																not accessible
7	334			334	203	309			309	188	345			345	210	
8	295			295	179	288			288	175	354			354	215	
9	321			321	195	313	321	315	316	192	439	729	445	538	327	
10	330	332	348	337	205	320	316	318	318	193	411	411	415	412	251	
11	368	363	358	363	221	324	326	324	325	197	372	375	378	375	228	
12	600	588	603	597	363	423	428	427	426	259	346	338	340	341	207	
13	396	404	403	401	244	328	328	327	328	199	357	375	380	371	225	
14	316	332	330	326	198	330	334	331	332	202	342	322	351	338	206	
15	343	357	333	344	209	332	333	326	330	201	333	333	334	333	203	
16	352	340	351	348	211	333	320	324	326	198	331	342	342	338	206	
17	441	423	421	428	260	334	332	328	331	201	336	332	339	336	204	
18	385	386	385	385	234	344	344	351	346	210	325	325	325	325	197	
19	356	368	367	364	221	414	417	410	414	251	339	334	348	340	207	
20	331	321	322	325	197	343	344	342	343	208	344	348	337	343	208	
21	336	326	322	328	199	320	316	314	317	192	327	327	327	327	199	
22	325	318	319	321	195	321	320	322	321	195	321	325	322	323	196	
23	315	316	315	315	192	315	315	314	315	191	306	309	306	307	187	
24	337	345	343	342	208	324	326	318	323	196	327	313	309	316	192	
25	333	336	348	339	206	318	322	324	321	195	318	309	316	314	191	
26	480	463	465	469	285	367	343	361	357	217	942	953	962	952	579	
27	298	291	295	295	179	322	327	324	324	197	446	453	457	452	275	
28	306	302	291	300	182	338	336	342	339	206	982	948	1172	1034	628	
29	288	300	286	291	177	442	446	459	449	273	766	769	756	764	464	
30	291	296	301	296	180	387	403	405	398	242	453	489	1620	854	519	
31	332	342	333	336	204	679	698	684	687	417						decay
32	356	351	351	353	214	567	566	572	568	345						decay
33	314	321	314	316	192	453	412	411	425	258						engraver
34	417	420	415	417	254	1029	1048	1045	1041	632	3757	3747	3144	3549	2157	engraver
35	518	517	518	518	315	784	776	795	785	477	3393	3380	3398	3390	2060	engraver, decay
36	1261	1265	1286	1271	772	1590	1580	1596	1589	965	2239	2343	1388	1990	1209	engraver
37	476	462	462	467	284	589	588	590	589	358	1111	1118	1086	1105	671	engraver
38	324	328	322	325	197	342	348	349	346	210	1681	1688	1696	1688	1026	
39	314	318	318	317	192	328	330	327	328	199	848	828	930	869	528	surface decay
40	327	326	327	327	198	346	344	343	344	209	806	825	807	813	494	C: decay
41	330	330	327	329	200	332	331	331	331	201	838	820	825	828	503	
42	324	319	321	321	195	338	337	339	338	205	399	400	390	396	241	C: surface rot
43	310	313	312	312	189	325	325	324	325	197	340	343	345	343	208	
44	318	314	312	315	191	327	327	330	328	199	339	338	332	336	204	
45	325	324	326	325	197	727	330	327	461	280	327	324	327	326	198	
46	309	307	303	306	186	301	313	320	311	189	336	337	338	337	205	
47	318	320	322	320	194	343	344	343	343	209	325	326	328	326	198	
48	387	385	382	385	234	398	399	393	397	241	350	346	348	348	211	

Appendix B2. Keel

Dimension: 16 x 20 in.
Test Interval: 6 ft.
Date: Jan. 12-13, 2006

Location [a] (ft)	Line A					Line B					Note
	Stress Wave Time (µs)				Velocity (µs/ft)	Stress Wave Time (µs)				Velocity (µs/ft)	
	1	2	3	Average		1	2	3	Average		
12	294	301	296	297	178	283	279	282	281.3	169	
18	280	274	266	273	164	301	295	292	296.0	178	
24	310	312	308	310	186	303	301	303	302.3	181	
30	428	428	424	427	256	400	384	379	387.7	233	
36	390	390	385	388	233	376	361	351	362.7	218	
41	686	670	668	675	405	618	606	615	613.0	368	
47	333	334	330	332	199	466	466	465	465.7	279	
53	381	382	385	383	230	387	387	388	387.3	232	
59	397	398	396	397	238	715	707	674	698.7	419	
65	658	636	627	640	384	435	433	433	433.7	260	
71	406	397	387	397	238	418	410	412	413.3	248	
77	429	423	417	423	254	667	661	679	669.0	401	
84	390	391	393	391	235	483	471	468	474.0	284	
90	399	397	397	398	239	482	476	474	477.3	286	
96	385	382	387	385	231	531	529	534	531.3	319	
103	373	372	369	371	223	396	388	390	391.3	235	
109	420	423	423	422	253	553	538	536	542.3	325	
115	746	735	740	740	444	718	715	697	710.0	426	big crack
122	337	342	336	338	203	362	362	356	360.0	216	
128	324	319	316	320	192	352	348	345	348.3	209	
134	380	379	381	380	228	417	426	424	422.3	253	
140	325	331	326	327	196	355	355	356	355.3	213	
146	320	322	322	321	193	378	373	374	375.0	225	
152	327	334	336	332	199	345	345	342	344.0	206	
158	312	311	310	311	187	408	414	414	412.0	247	
164	320	322	318	320	192	352	350	349	350.3	210	
171	307	309	306	307	184	350	327	328	335.0	201	
178	276	277	277	277	166	319	321	320	320.0	192	
184	300	304	303	302	181	334	335	337	335.3	201	
188	312	310	312	311	187	308	308	303	306.3	184	
194	310	308	304	307	184	316	318	320	318.0	191	

[a] Numbers represent distance from aft to fore of the ship.

Appendix B3. Main Deck Beams above Tween Deck (Portside)

Dimensions: 14 ½ x 14 ¼ in.
Test Interval: Spot check
Date: Jan. 11, 2006

Frame Reference No.	Location 1					Location 2					Location 3				
	Stress Wave Time (µs)				Velocity (µs/ft)	Stress Wave Time (µs)				Velocity (µs/ft)	Stress Wave Time (µs)				Velocity (µs/ft)
	1	2	3	Avg.		1	2	3	Avg.		1	2	3	Avg.	
12.5	242	244	244	243	201	228	224	222	225	186					
14.5	256	256	259	257	209	247	247	244	246	200					
16.5	2246	2206	2196	2216	1803	1654	1632	1684	1657	1348	2035	1419	1418	1624	1659
18.5	1476	1562	1870	1636	1331	2013	2253	2245	2170	1766					
20.5	790	792	796	793	645	403	393	384	393	320					
22	396	399	380	392	324	283	274	272	276	229					
24	1735	1722	1722	1726	1429	1495	1410	1476	1460	1209					
26	1316	1303	1306	1308	952	3460			3460	2516	194	204	196	198	202

Frame Reference No.	Location 4					Location 5					Location				
	Stress Wave Time (µs)				Velocity (µs/ft)	Stress Wave Time (µs)				Velocity (µs/ft)	Stress Wave Time (µs)				Velocity (µs/ft)
	1	2	3	Avg.		1	2	3	Avg.		1	2	3	Avg.	
12.5															
14.5															
16.5	1063	1046	1041	1050	1072	1242	1238	980	1153	1178	2035	1419	1418	1624	1659
18.5															
20.5															
22															
24															
26	310	392	302	335	342	324	307	321	317	324	194	204	196	198	202

Appendix B4. Main Deck Beams at Rear Cargo Hold (Portside)

Dimensions:	**14 ½ x 14 ¼ in.**
Test Interval:	**Spot check**
Date:	**Jan. 11, 2006**

	Location														
Frame Reference No.	1					2					3				
	Stress Wave Time (μs)				Velocity (μs/ft)	Stress Wave Time (μs)				Velocity (μs/ft)	Stress Wave Time (μs)				Velocity (μs/ft)
	1	2	3	Avg.		1	2	3	Avg.		1	2	3	Avg.	
38.5	849	1004	860	904	736	270	266	278	271	221	277	273	279	276	225
40	754	928	777	820	678	532	531	541	535	442	247	249	249	248	206
42	1195	1191	1186	1191	969	408	403	402	404	329	225	229	236	230	187
44	211	217	214	214	177	247	253	249	250	207	512	518	518	516	427
45.5	762	757	759	759	628	312	304	306	307	254	268	270	268	269	222
47.5	520	517	519	519	429	634	640	645	640	529	244	250	244	246	204

	Location									
Frame Reference No.	4					5				
	Stress Wave Time (μs)				Velocity (μs/ft)	Stress Wave Time (μs)				Velocity (μs/ft)
	1	2	3	Avg.		1	2	3	Avg.	
38.5	715	692	714	707	575	462	471	460	464	378
40	561	567	592	573	474	876	831	824	844	698
42	283	284	280	282	230	232	235	232	233	190
44	342	334	346	341	282	253	254	252	253	209
45.5	298	301	302	300	249	586	588	589	588	486
47.5	358	358	356	357	296	350	354	355	353	292

Appendix B5. Main Deck Stringers

Dimensions: 11 ½ x 13 ½ in.
Test Interval: 5 ft.
Date: 1/12/2006

Portside Side Stringer

Location [a]	Stress wave time (µs) 1	2	3	Average	Velocity (µs/ft)	Note
1	754	759	752	755	805	
2	226	222	219	222	237	
3	1036	1148	1036	1073	1145	
4	1810	1789	1814	1804	1925	
5	659	652	666	659	703	
6	861	866	867	865	922	repaired
7						repaired
8						repaired
9						repaired
10			- -			repaired
11	266	260	265	264	281	
12	180	169	174	174	186	
13	4117	4069	4035	4074	4345	
14	932	916	906	918	979	
15	490	494	489	491	524	
16	867	859	886	871	929	
17	193	195	196	195	208	

[a] Numbers represent 5-ft intervals from fore to aft of the ship

Starboard Side Stringer

Location [a]	Stress wave time (µs) 1	2	3	Average	Velocity (µs/ft)	Note
1	615	619	609	614	655	
2	318	314	314	315	336	
3	444	439	444	442	472	
4	644	646	642	644	687	
5	1381	1377	1394	1384	1476	
6	249	246	254	250	266	
7	2574	2548	2582	2568	2739	repaired
8	1862	1575	1550	1662	1773	repaired
9	1953	2158	2229	2113	2254	netting in way
10						netting in way
11						netting in way
12	1632	1620	1593	1615	1723	
13	8977	8972	8935	8961	9559	
14	540	544	540.	541	577	
15	459	452	429	447	476	
16	222	210	207	213	227	
17	322	327	319	323	344	

[a] Numbers represent 5-ft intervals from fore to aft of the ship

Appendix B6. Pointers

Dimensions: 14 x 13 in.
Test Interval: 4 ft.
Date: 1/12/2006

Starboard Pointer

Location [a]	Stress wave time (µs)				Velocity (µs/ft)	Note
	1	2	3	Average		
1	226	249	235	237	210	
2	244	246	246	245	218	
3	214	218	214	215	191	
4	224	225	224	224	199	
5	225	226	224	225	200	
6	276	260	261	266	236	big crack
7	547	544	528	540	480	big crack
8	585	582	582	583	518	big crack

[a] Numbers represent 4-ft intervals from fore to aft of the ship

Portside Pointer

Location [a]	Stress wave time (µs)				Velocity (µs/ft)	Note
	1	2	3	Average		
9	226	230	226	227	202	
10	244	252	241	246	218	
11	229	223	223	225	200	
12	226	224	229	226	201	
13	243	254	246	248	220	
14	204	218	218	213	190	
15	325	321	324	323	287	
16	524	511	516	517	460	big crack

[a] Numbers represent 4-ft intervals from fore to aft of the ship

Appendix B7. Pillars

Dimensions: 15 x 15 ½ in.
Test Interval: Spot check
Date: 1/11/2006

Pillar No.	Test Location	Test Direction	Floor level	Stress Wave Time (µs) 1	2	3	Avg.	Velocity (µs/ft)
A	1	Fore-aft	Lower	344	342	345	344	266
A	1	Port-starboard	Lower	462	451	440	451	349
A	2	Fore-aft	Lower	495	494	493	494	382
A	2	Port-starboard	Lower	1011	1026	1014	1017	787
A	1	Fore-aft	Middle	459	469	468	465	360
A	2	Fore-aft	Middle	822	825	823	823	638
A	1	Port-starboard	Upper	214	213	214	214	166
B	1	Fore-aft	Lower	702	703	708	704	545
B	1	Port-starboard	Lower	540	540	538	539	418
B	2	Fore-aft	Lower	668	623	627	639	495
B	2	Port-starboard	Lower	314	312	308	311	241
B	1	Fore-aft	Middle	321	321	327	323	250
B	2	Fore-aft	Middle	1034	1030	1002	1022	792
B	1	Port-starboard	Upper	253	250	247	250	193
C	1	Fore-aft	Lower	608	609	609	609	471
C	1	Port-starboard	Lower	1012	919	1011	981	759
C	2	Fore-aft	Lower	483	472	465	473	366
C	2	Port-starboard	Lower	762	721	756	746	578
C	1	Fore-aft	Middle	300	315	308	308	238
C	2	Fore-aft	Middle	688	682	682	684	530
D	1	Fore-aft	Lower	331	343	347	340	263
D	1	Port-starboard	Lower	686	614	685	662	512
D	2	Fore-aft	Lower	482	484	477	481	372
D	2	Port-starboard	Lower	402	394	402	399	309
D	1	Fore-aft	Middle	416	404	402	407	315
D	2	Fore-aft	Middle	368	357	346	357	276
E	1	Port-starboard	Lower	243	242	237	241	186
E	2	Port-starboard	Lower	258	261	255	258	200
F	1	Port-starboard	Lower	291	297	295	294	228
F	2	Port-starboard	Lower	316	301	304	307	238

Appendix B8. Hold Stanchions

Dimensions: 7 ½ x 14 ½ in.
Test Interval: Spot check
Date: 1/11/2006

No.[a]	Test Line	Test Direction	Floor level	Stress Wave Time (μs) 1	2	3	Avg.	Velocity (μs/ft)
0	A	Fore-aft	Lower	817	811	780	803	584
0	B	Fore-aft	Lower	496	510	441	482	351
1	A	Fore-aft	Lower	727	723	735	728	514
1	B	Fore-aft	Lower	668	660	663	664	468
2	A	Fore-aft	Lower	386	393	403	394	326
4	A	Fore-aft	Lower	226	226	224	225	186
6	A	Fore-aft	Lower	234	229	229	231	191
8	A	Fore-aft	Lower	235	241	232	236	195
9	A	Fore-aft	Lower	246	243	237	242	200
12	A	Fore-aft	Lower	231	225	235	230	191
14	A	Fore-aft	Lower	236	240	236	237	196
16	A	Fore-aft	Lower	240	242	242	241	200
19	A	Fore-aft	Lower	180	177	180	179	179

[a] Stanchion numbers move from aft to fore of the ship.

Appendix C

Resistance Micro-Drilling Plots

C1. Keelsons

C2. Keel

C3. Frame #8

C4. Frame #32

C5. Frame #48

C6. Main Deck Beams

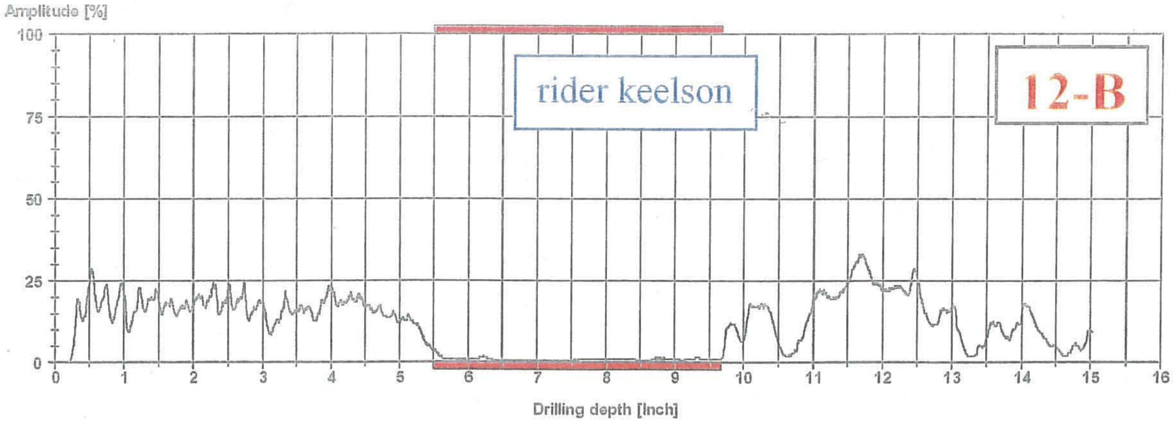
C7. Beam Clamps & Bulwarks

C8. Frames from Outside Hull Openings

Appendix C1

Resistance Micro-Drilling Plots

Keelson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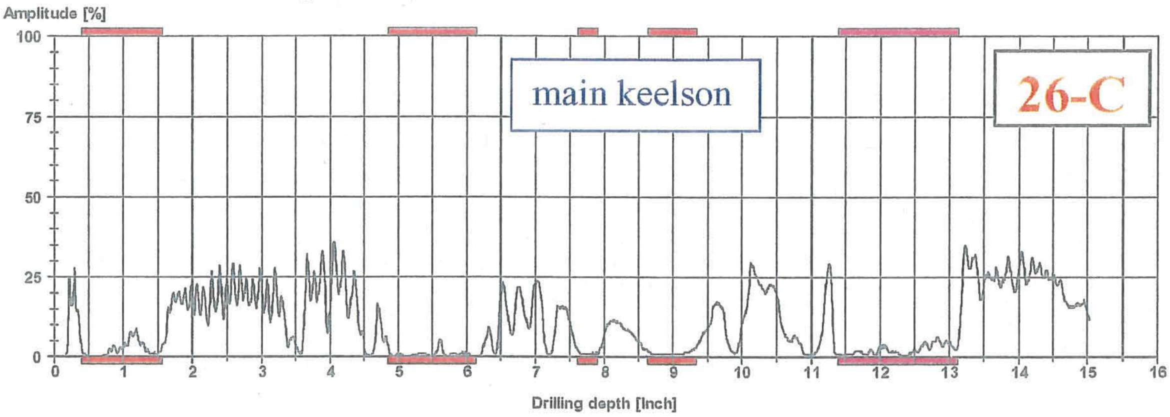
Drilling depth [inch]
rider keelson
12-B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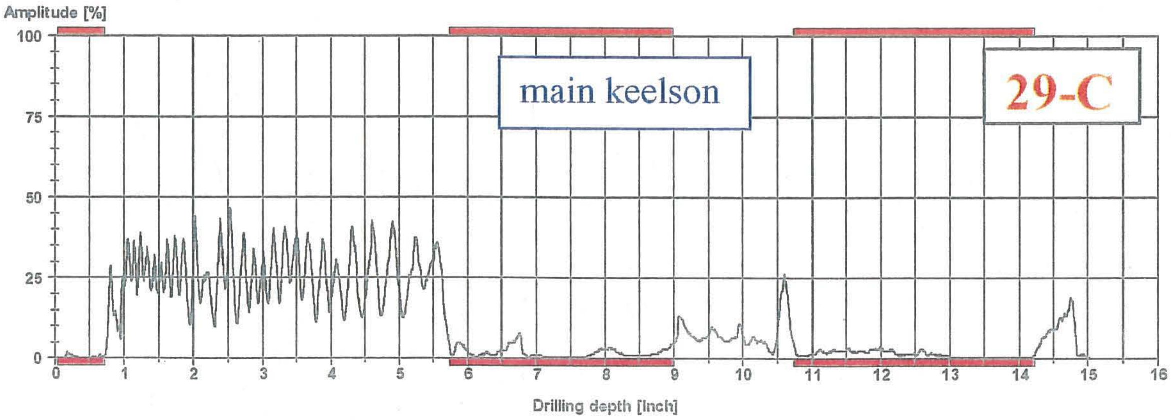
Drilling depth [inch]
main keelson
26-C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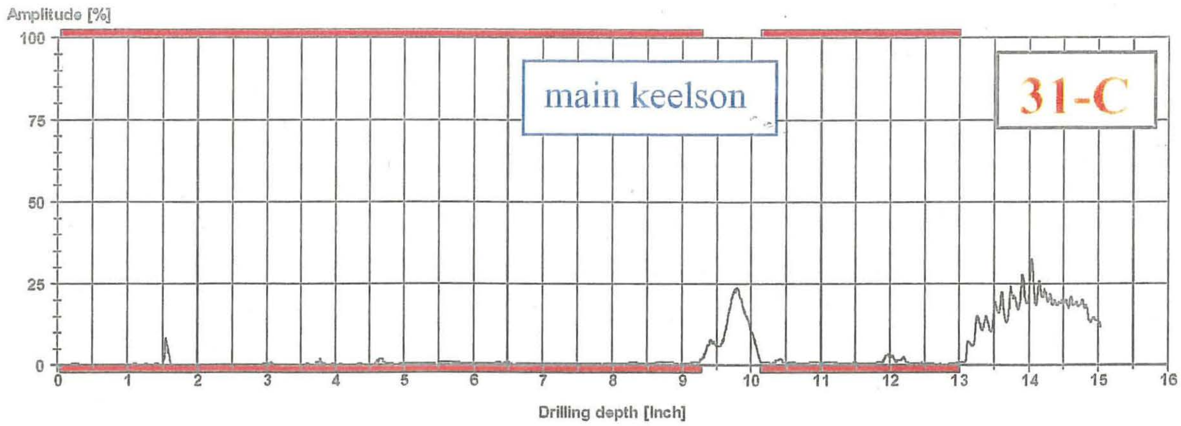
Drilling depth [inch]
main keelson
29-C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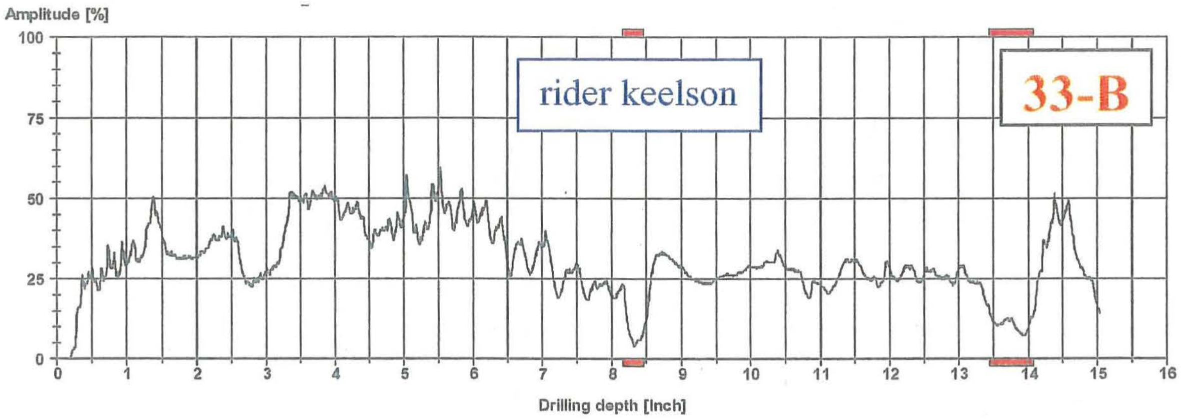
Drilling depth [Inch]
main keelson
31-C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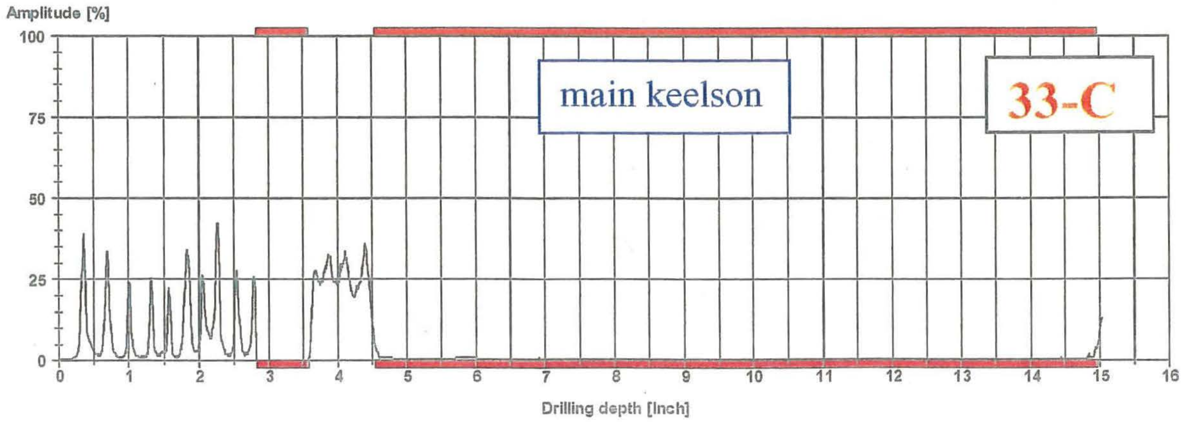
Drilling depth [Inch]
rider keelson
33-B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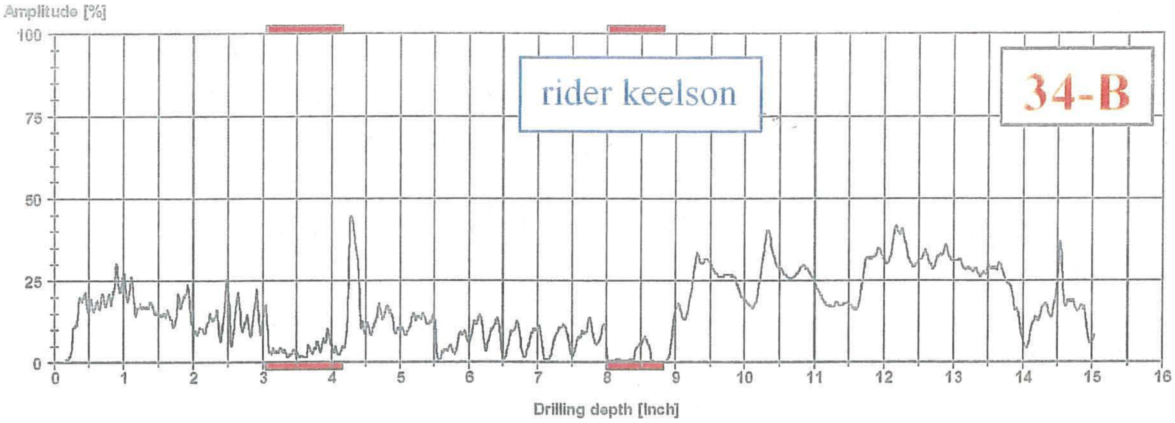
Drilling depth [Inch]
main keelson
33-C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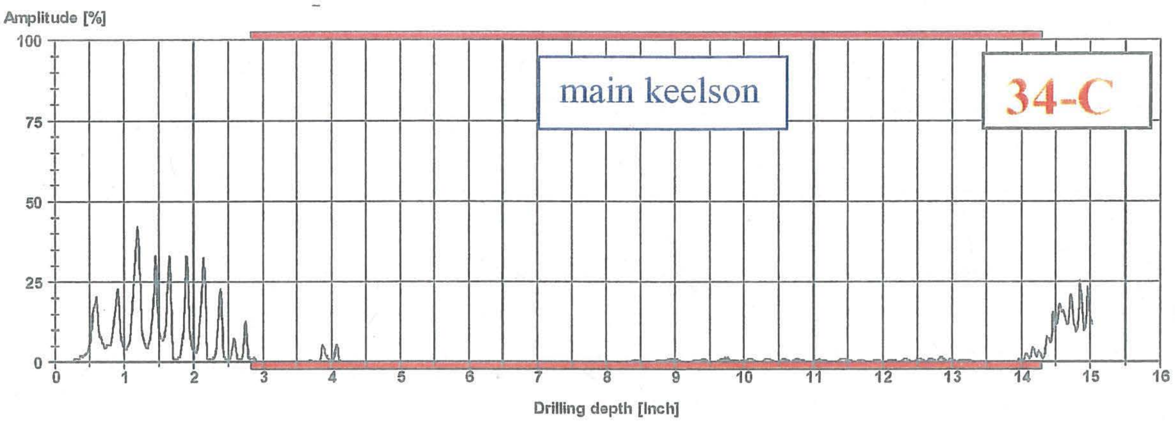
Drilling depth [Inch]
rider keelson
34-B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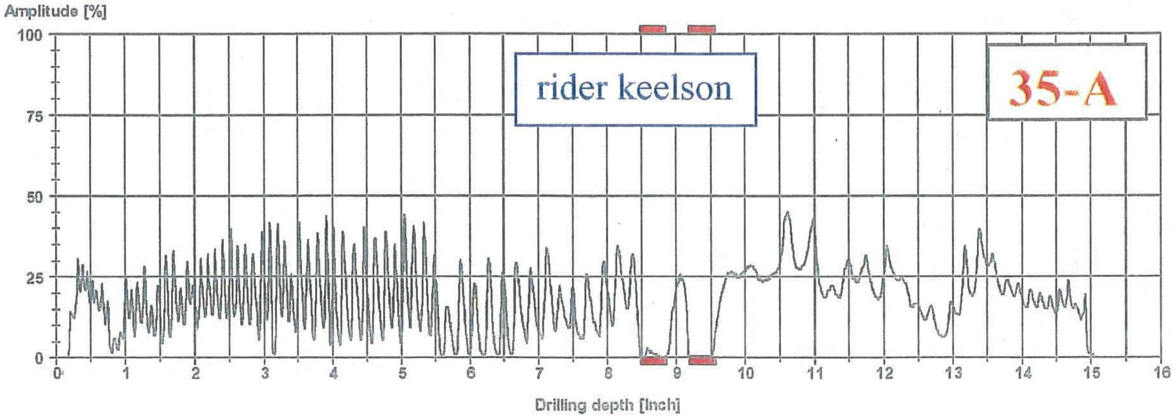
Drilling depth [Inch]
main keelson
34-C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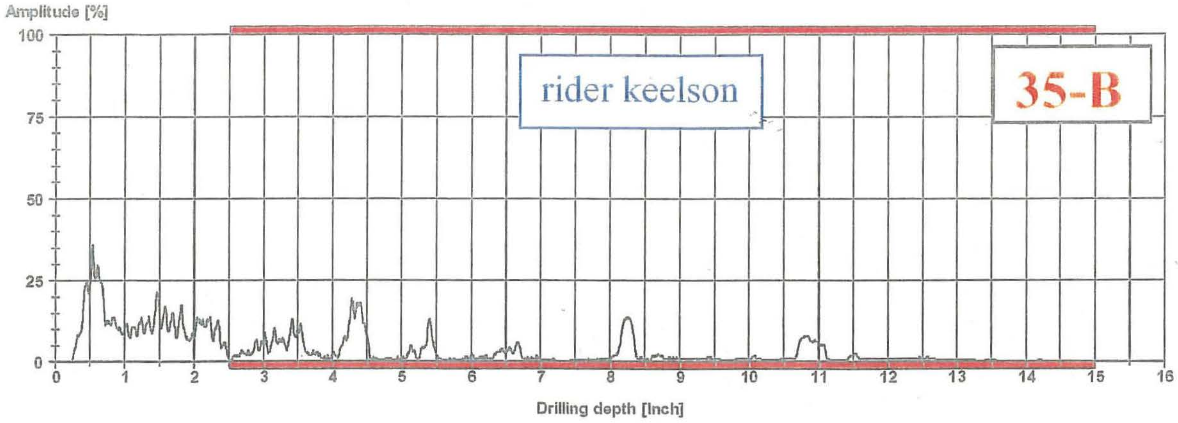
Drilling depth [Inch]
rider keelson
35-A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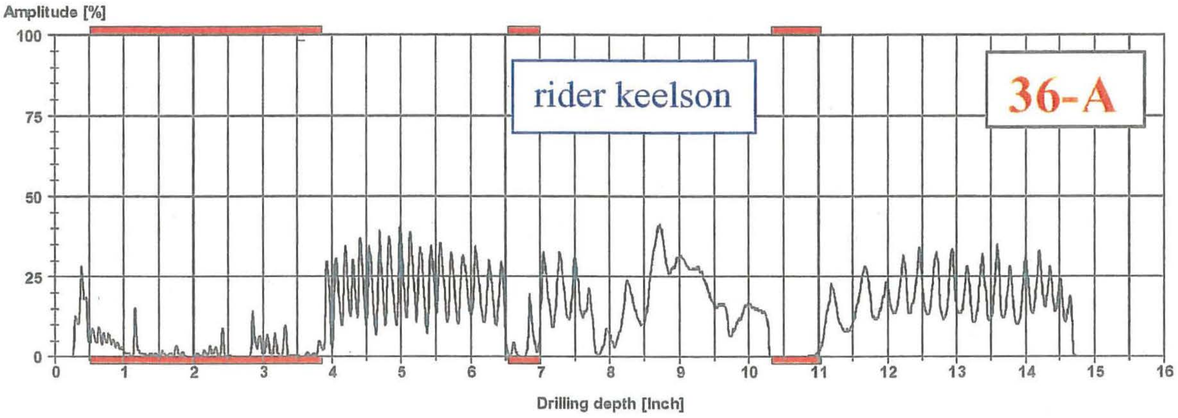
Drilling depth [Inch]
rider keelson
35-B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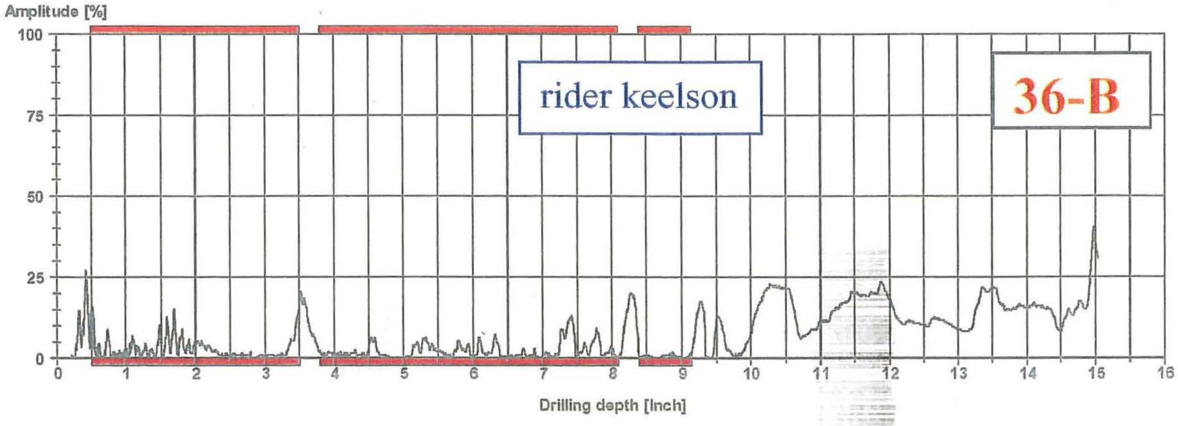
Drilling depth [Inch]
rider keelson
36-A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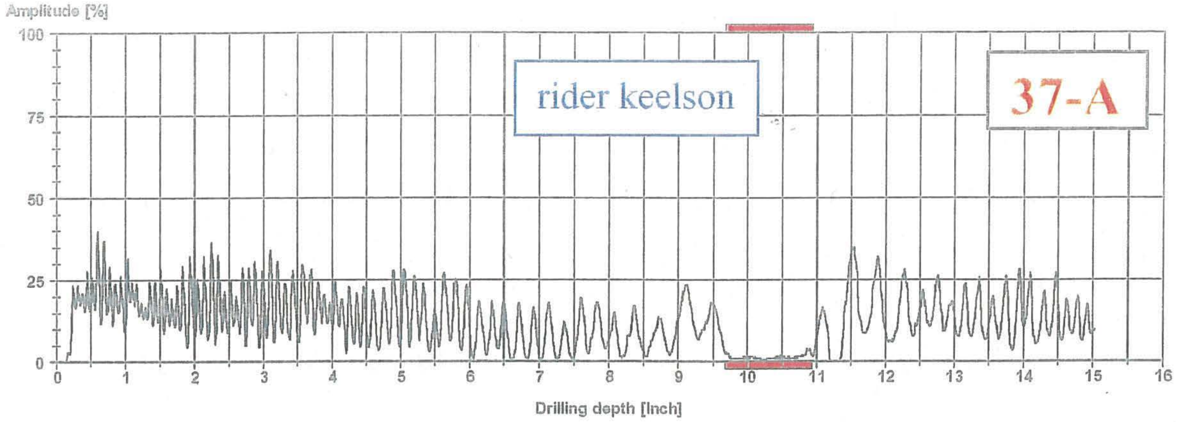
Drilling depth [Inch]
rider keelson
36-B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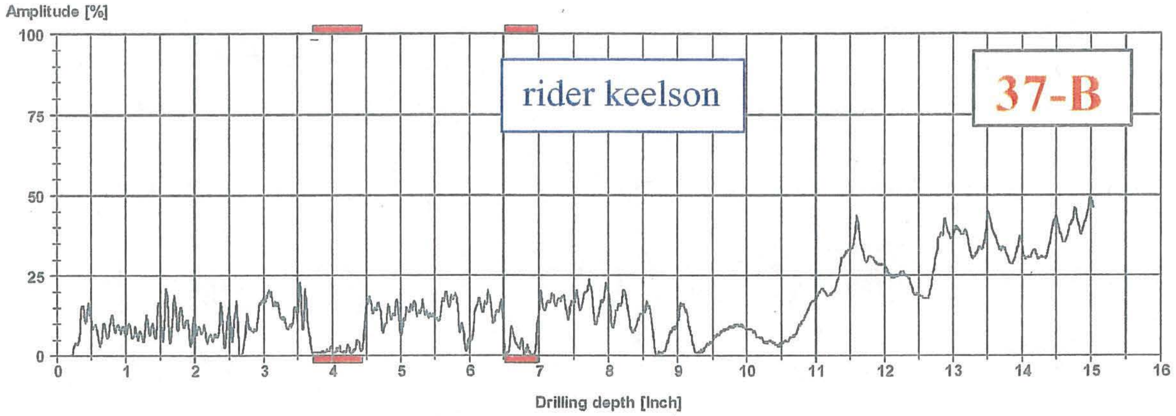
Drilling depth [Inch]
rider keelson
37-A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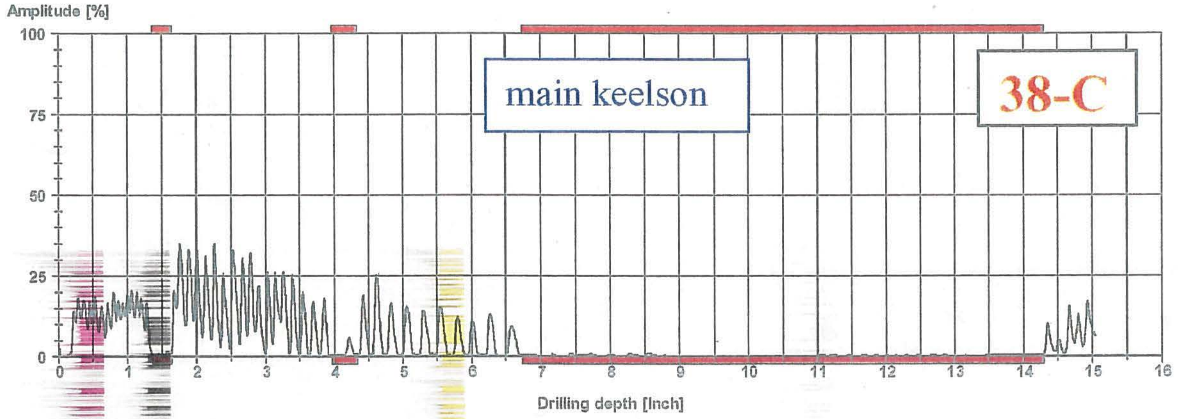
Drilling depth [Inch]
rider keelson
37-B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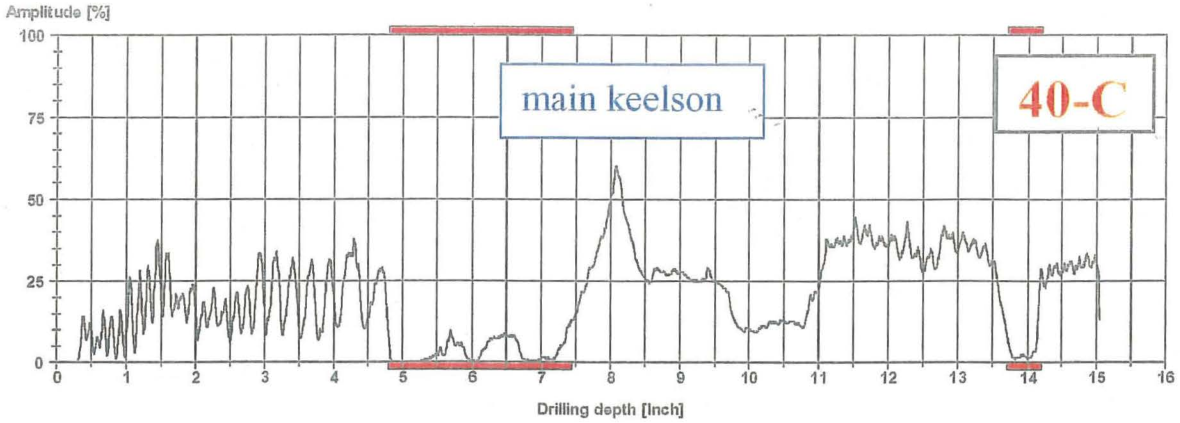
Drilling depth [Inch]
main keelson
38-C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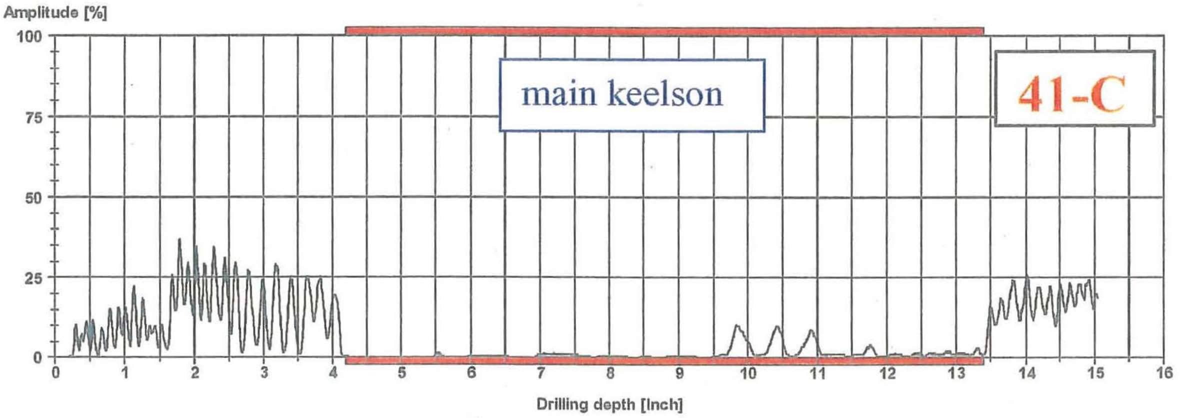
Drilling depth [Inch]
main keelson
40-C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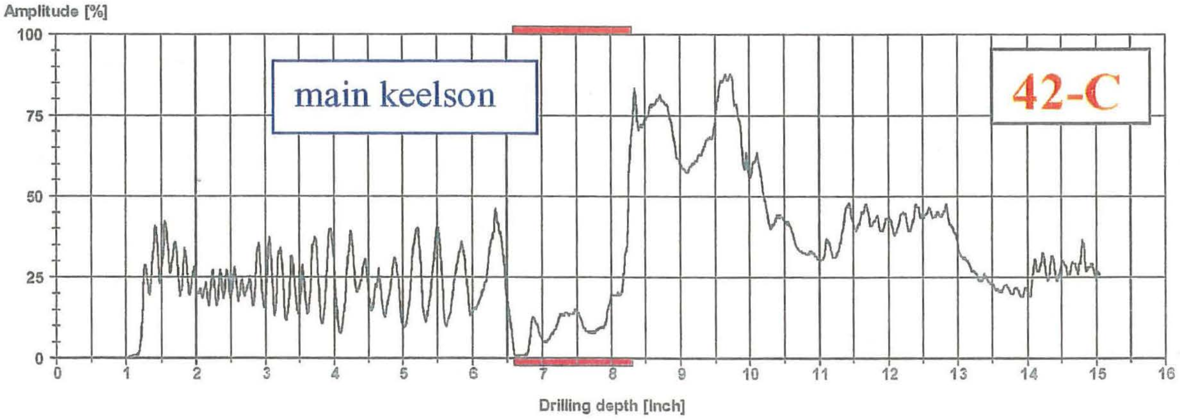
Drilling depth [Inch]
main keelson
41-C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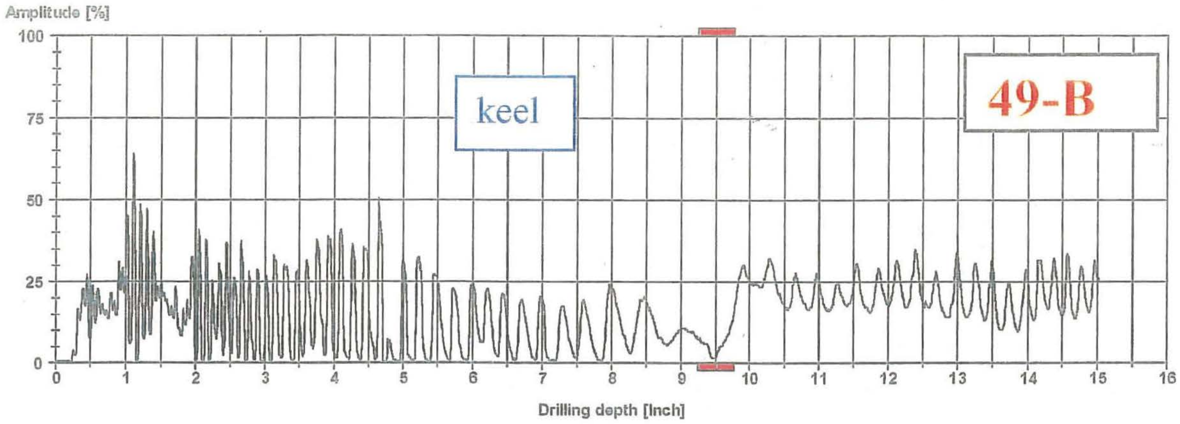
Drilling depth [Inch]
main keelson
42-C

Appendix C2

Resistance Micro-Drilling Plots

Keel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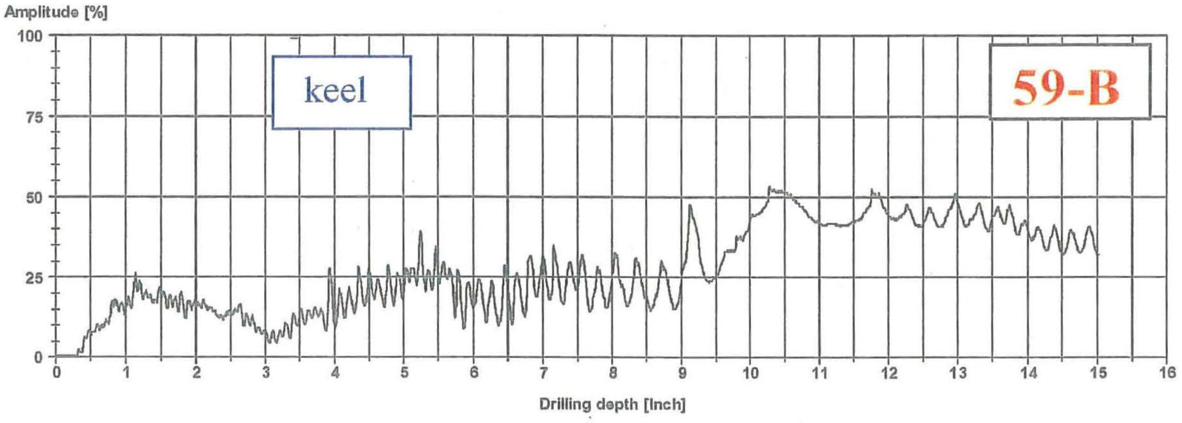
Drilling depth [Inch]
keel
49-B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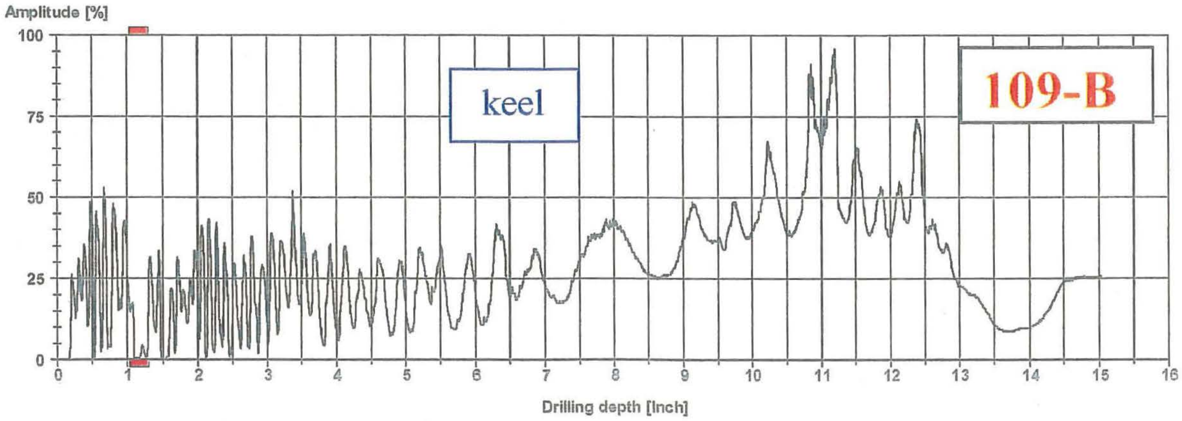
Drilling depth [Inch]
keel
59-B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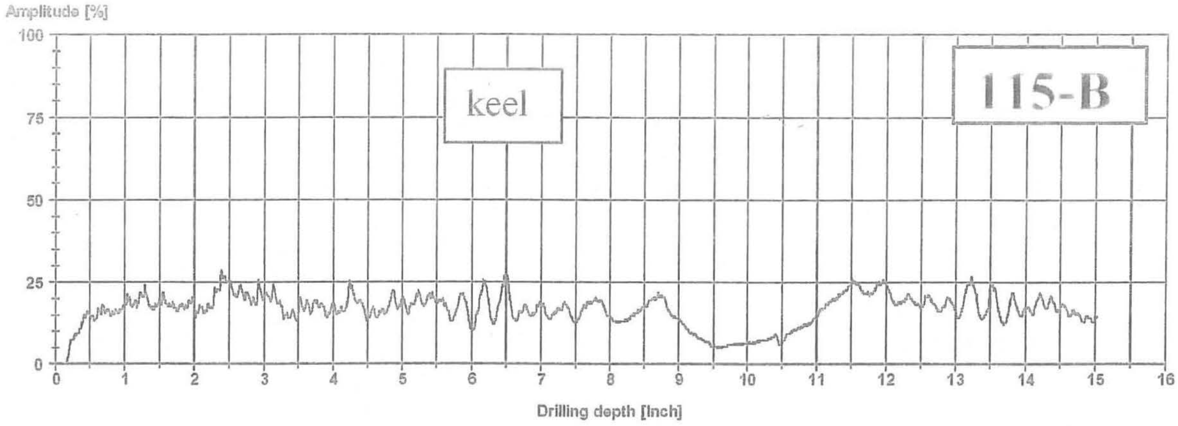
Drilling depth [Inch]
keel
109-B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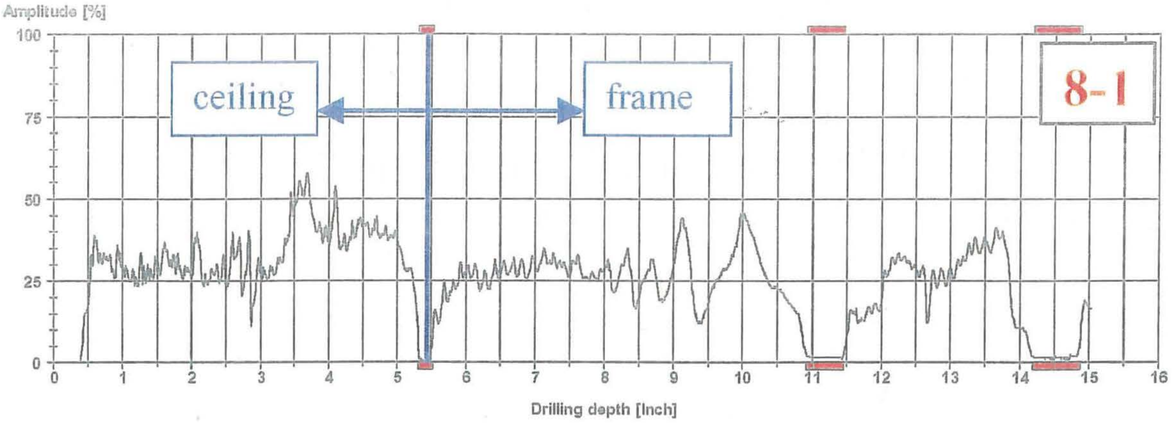
Drilling depth [Inch]

Appendix C3

Resistance Micro-Drilling Plots

Hull Frame #8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frame
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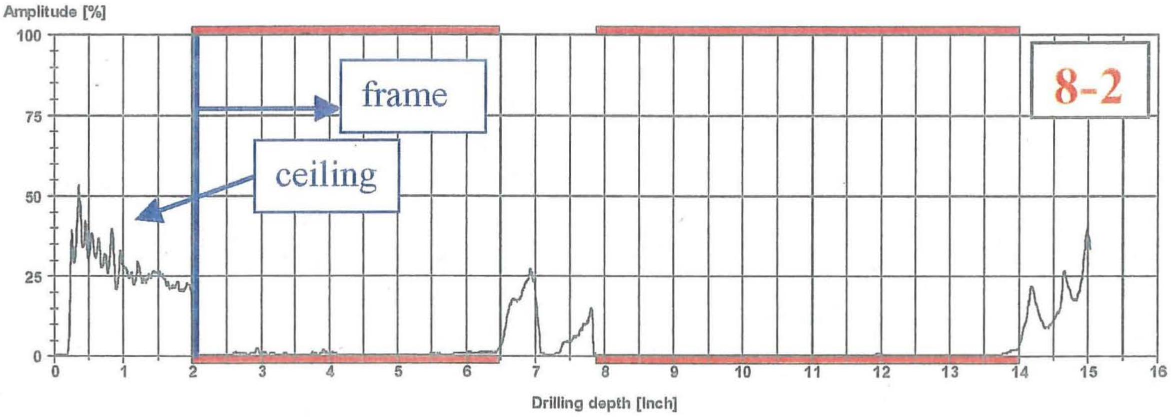
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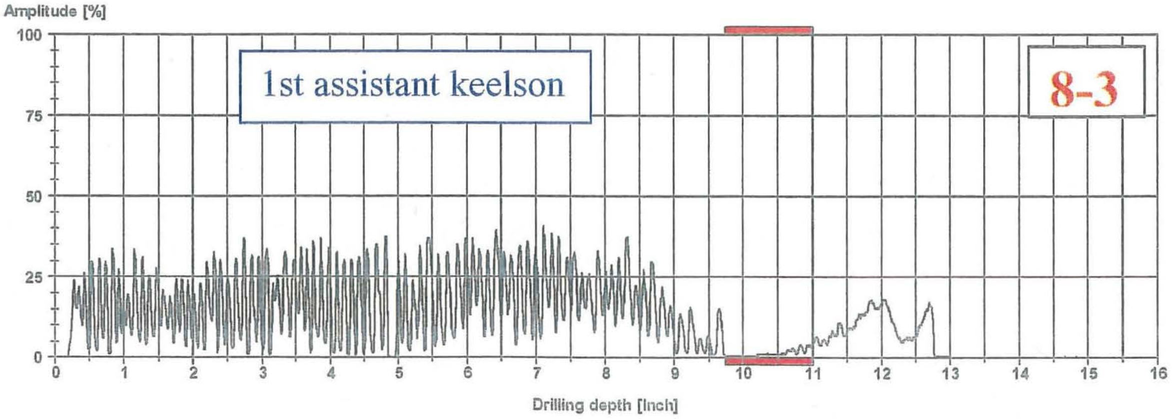
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1st assistant keelson
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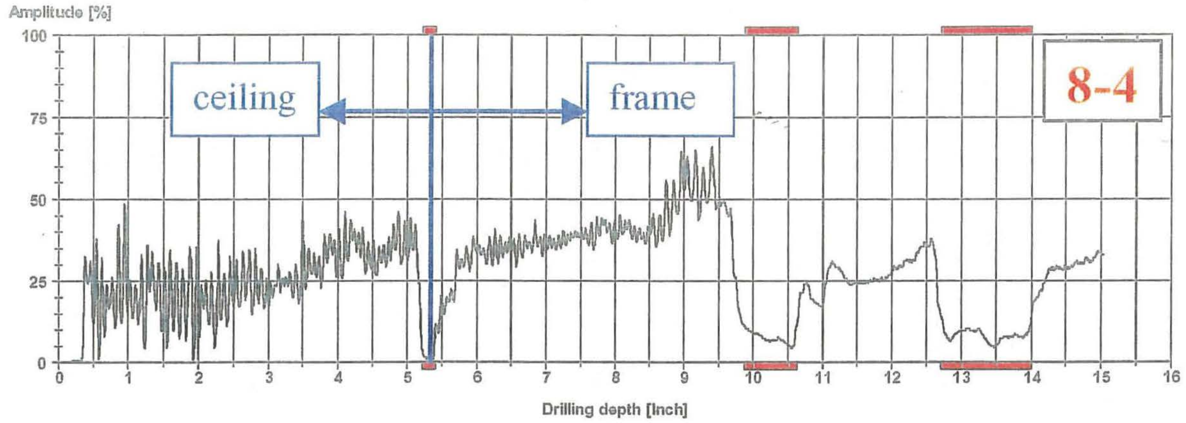
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ceiling
frame
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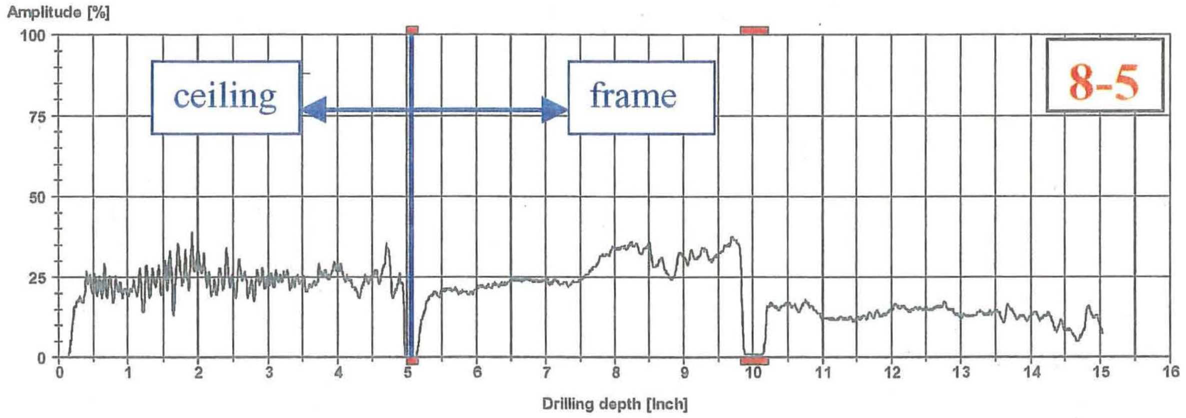
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Drilling depth [Inch]
ceiling
frame
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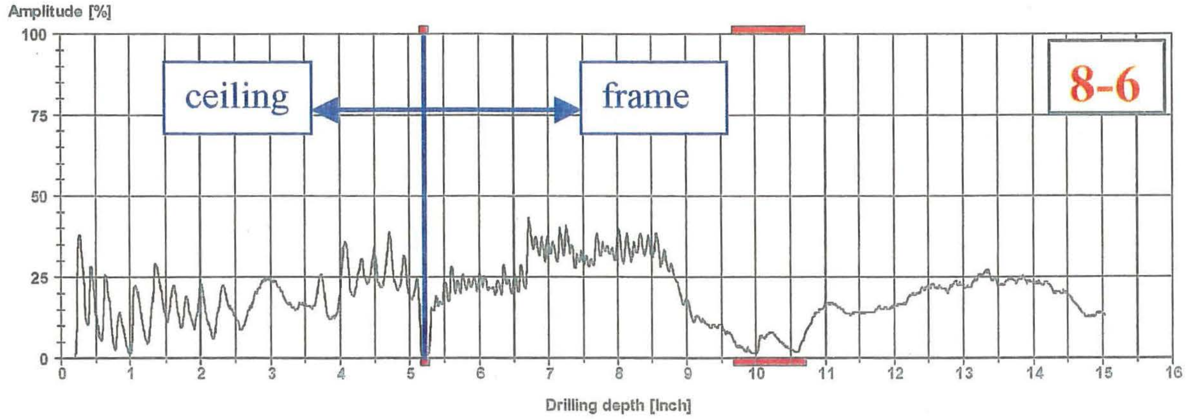
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frame
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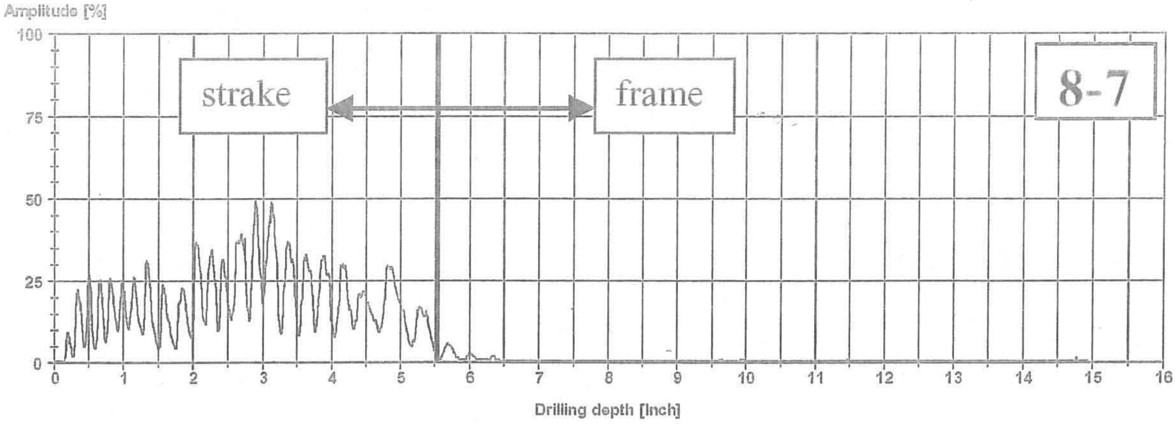
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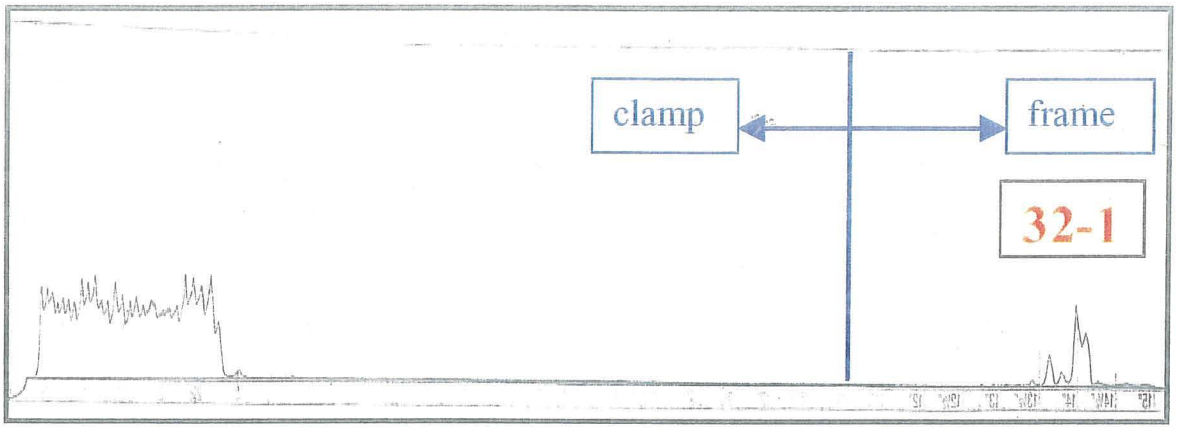
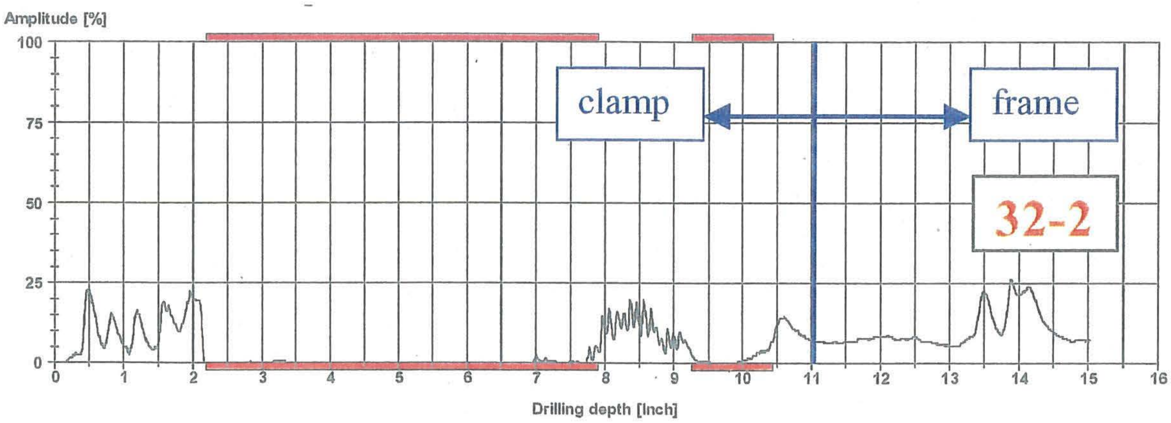
75
50
25
0
strake
frame
8-7
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

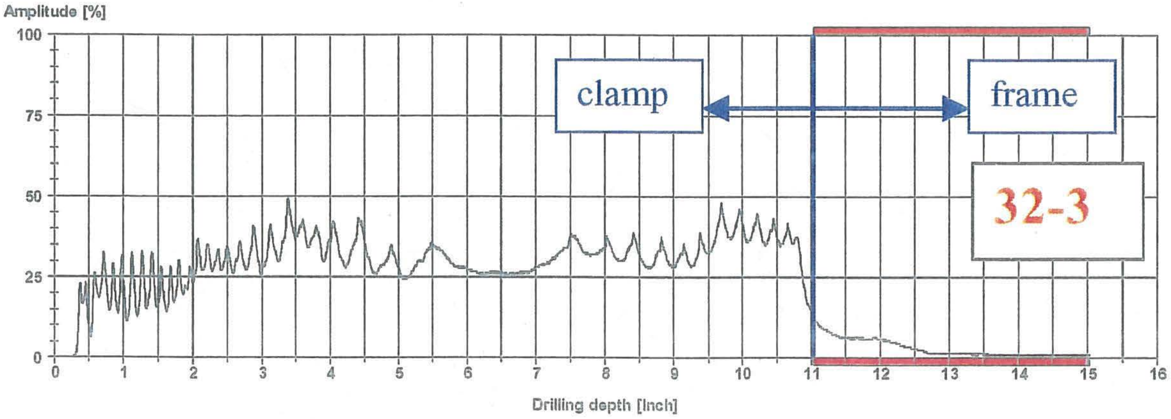
Appendix C4

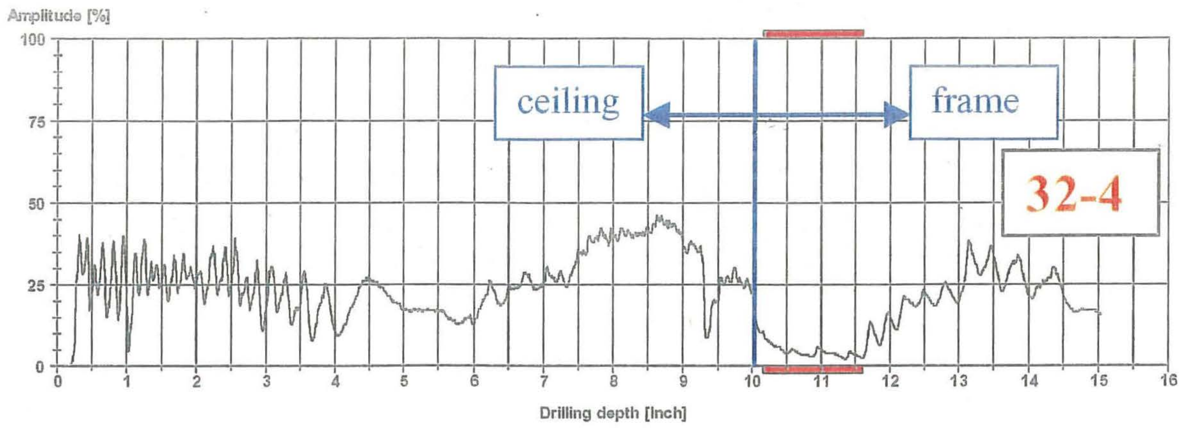
Resistance Micro-drilling Plots

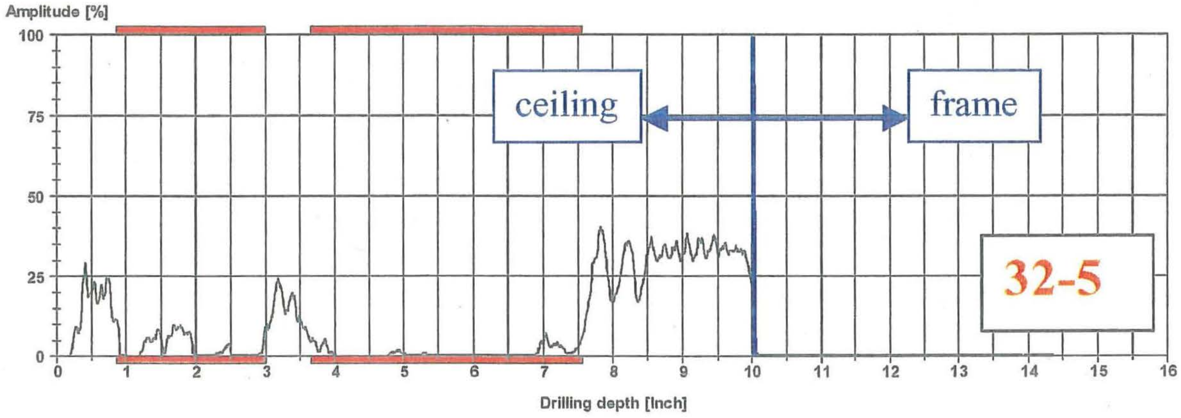
Hull Frame #32

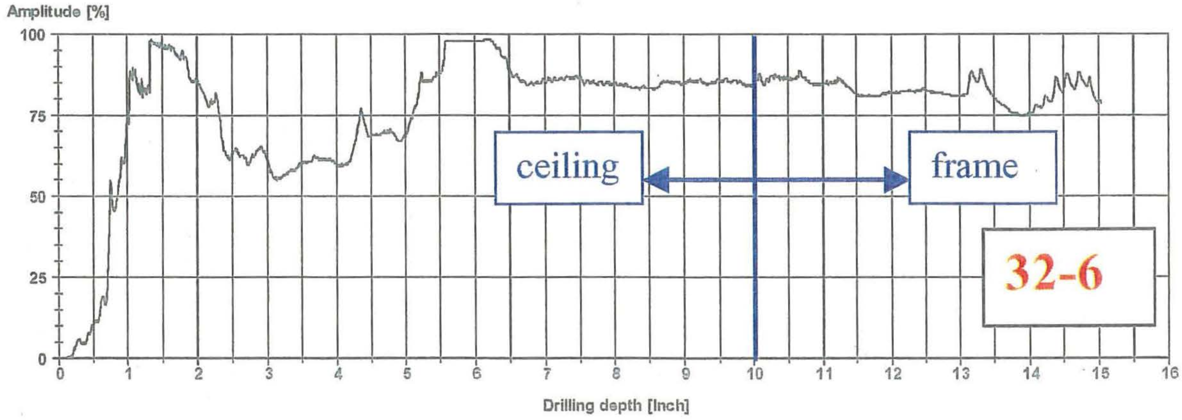

clamp
frame
32-1

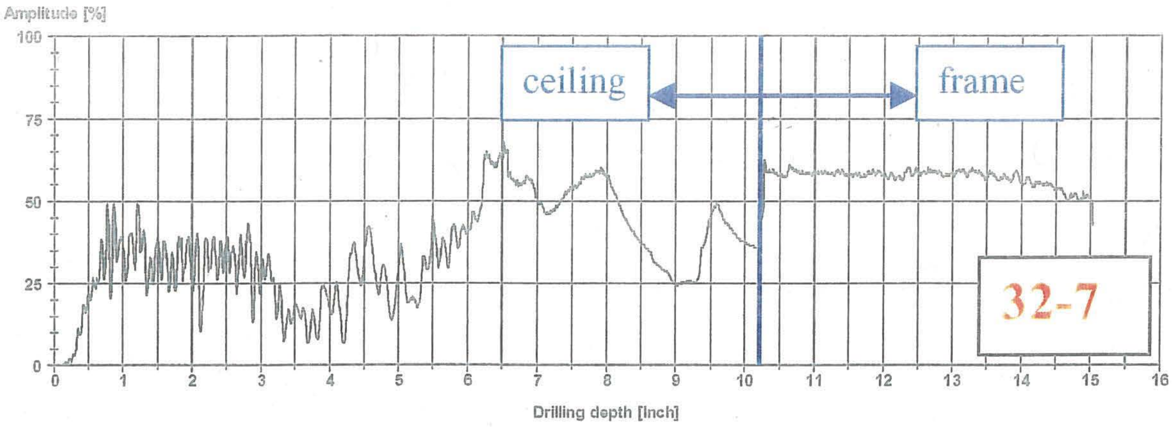

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
clamp
frame
32-2

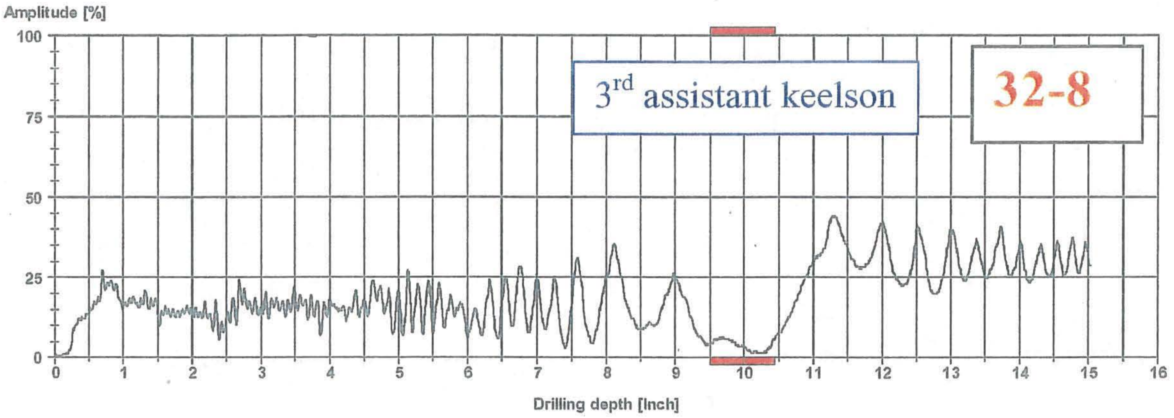

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
clamp
frame
32-3

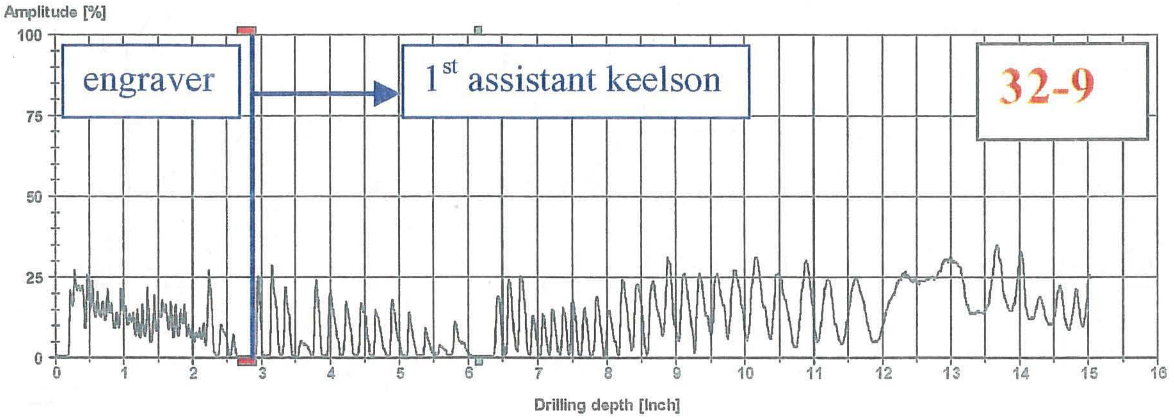

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
ceiling
frame
32-4

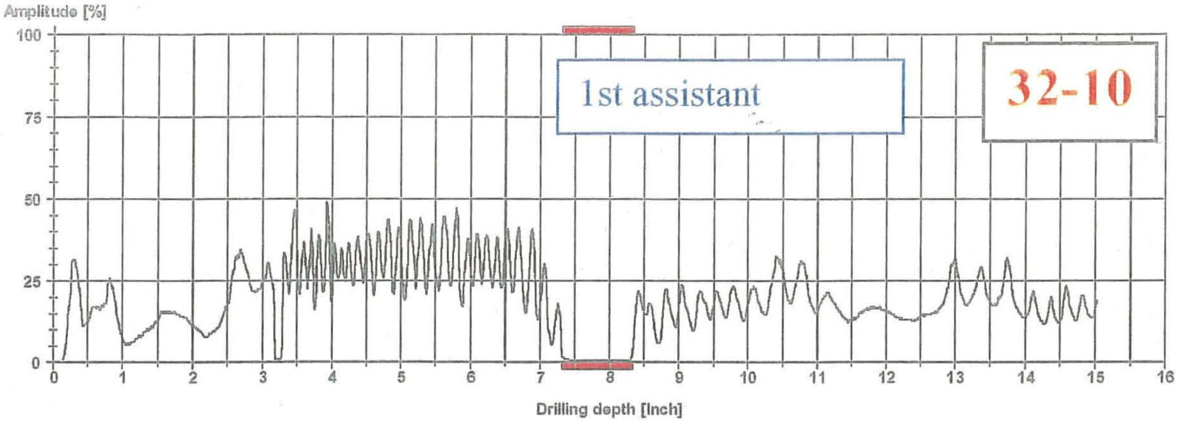

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
ceiling
frame
32-5

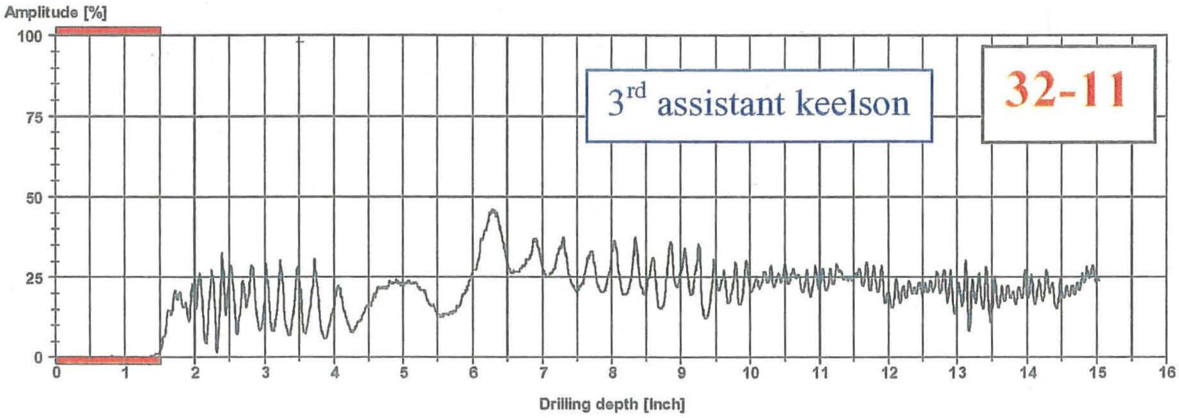

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
ceiling
frame
32-6


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
ceiling
frame
32-7


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
3rd assistant keelson
32-8


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
engraver
1st assistant keelson
32-9


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
1st assistant
32-10


Amplitude [%]
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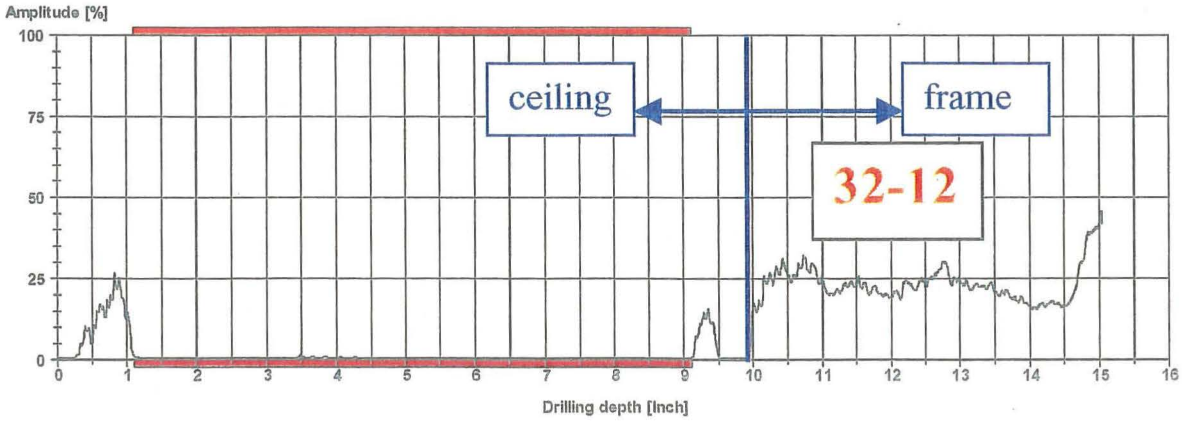
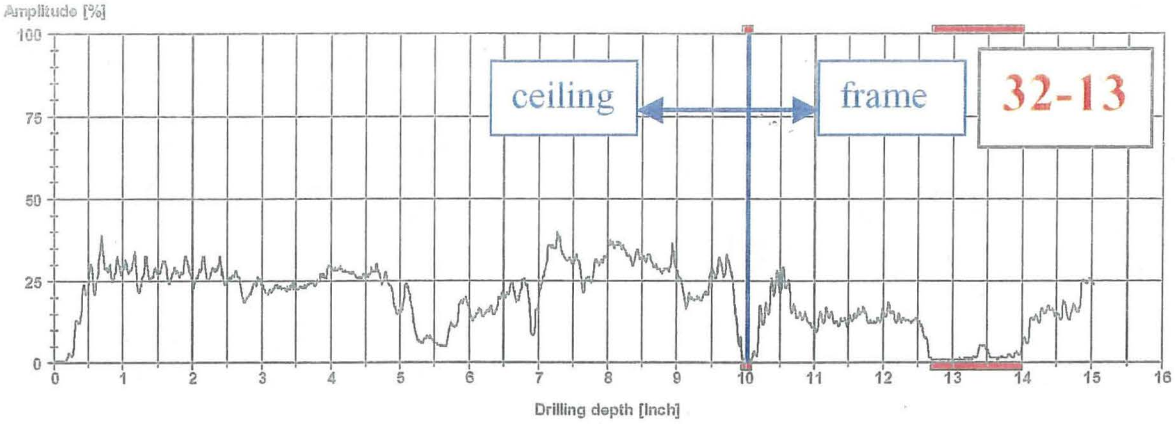
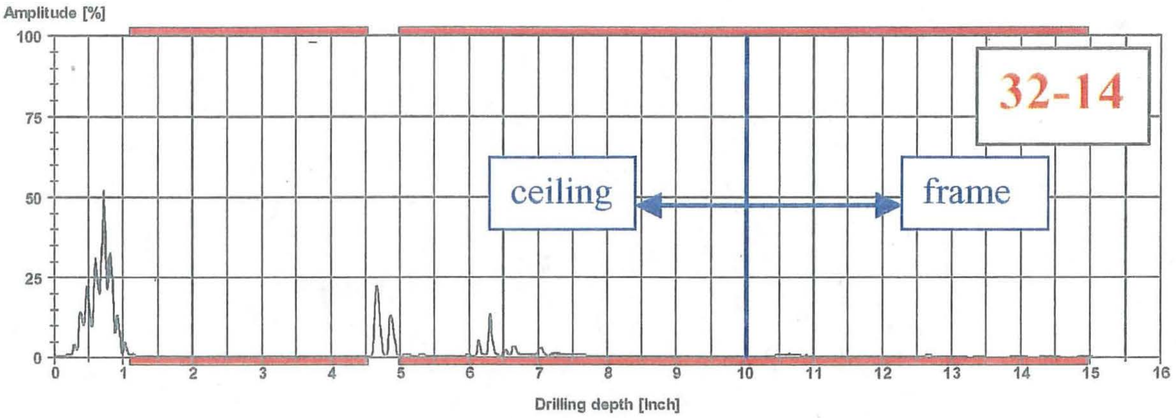
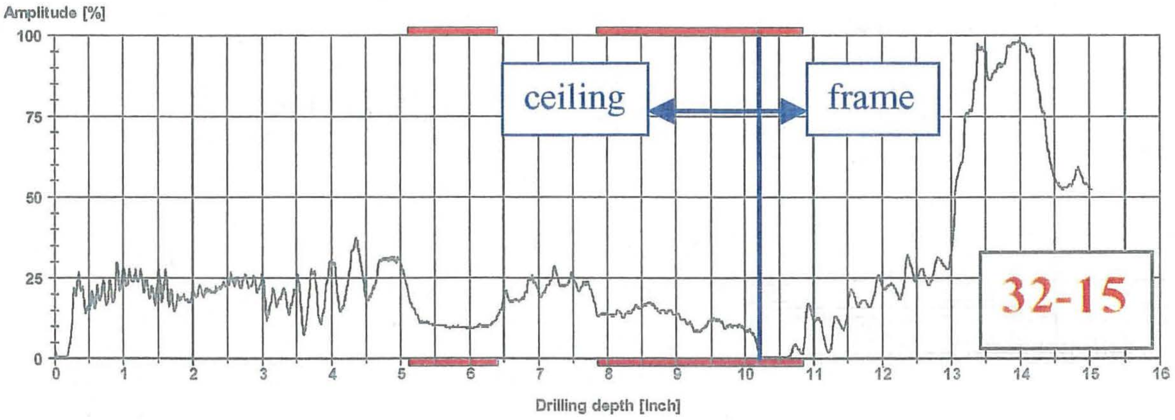
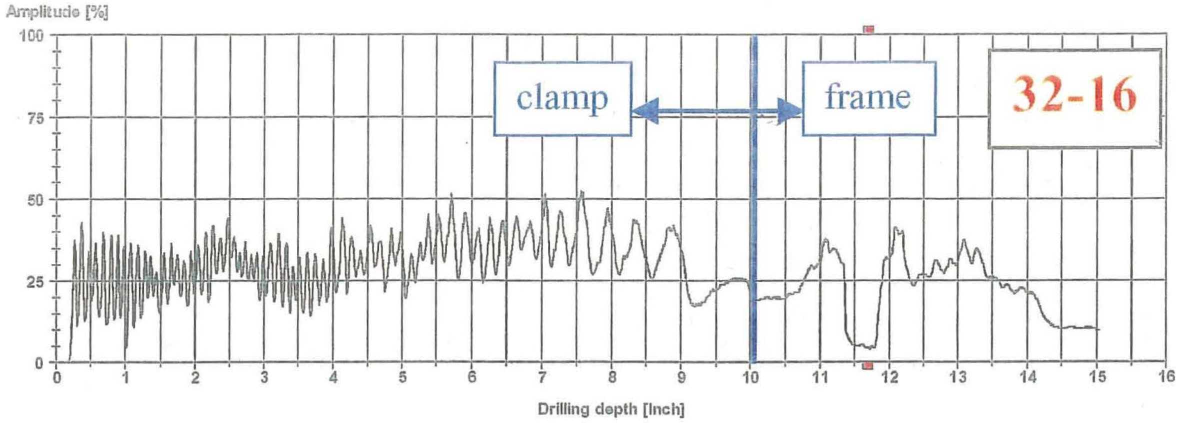
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
3rd assistant keelson
32-11


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
ceiling
frame
32-12


Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
ceiling
frame
32-13


Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
ceiling
frame
32-14


Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
ceiling
frame
32-15


Amplitude [%]
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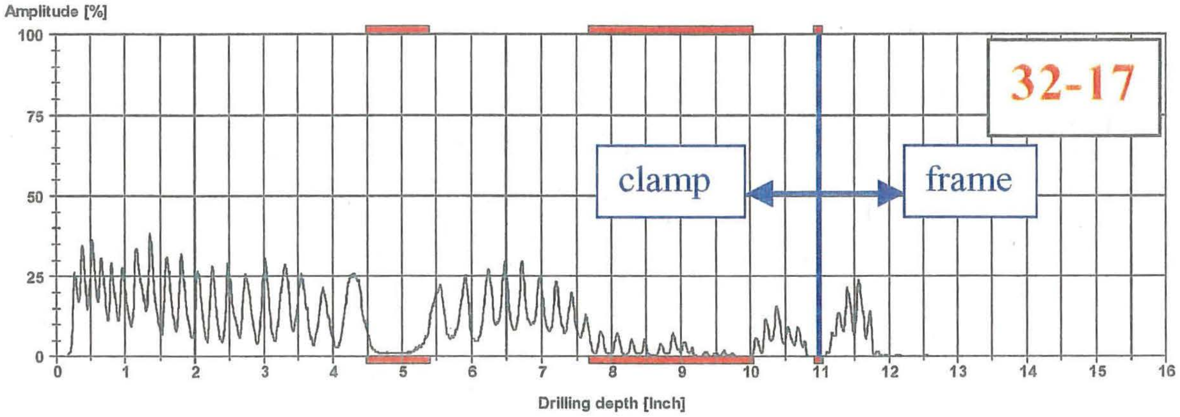
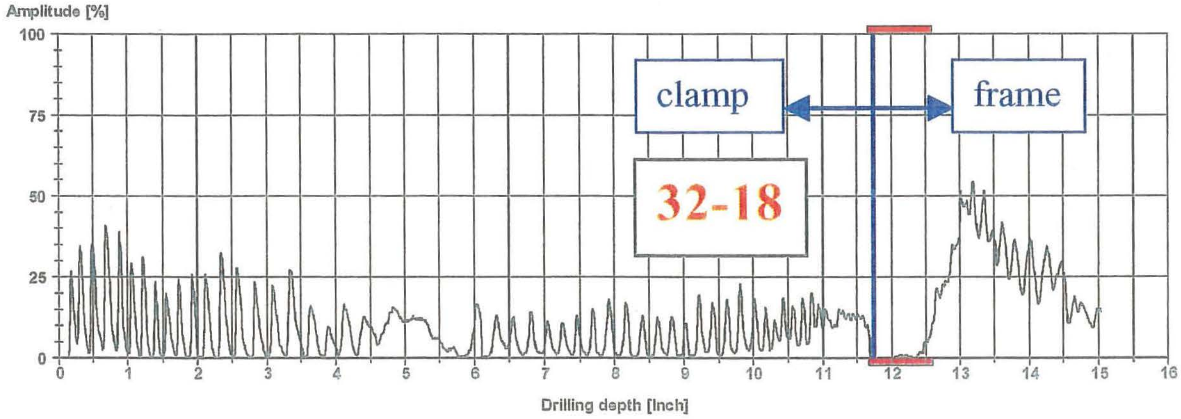
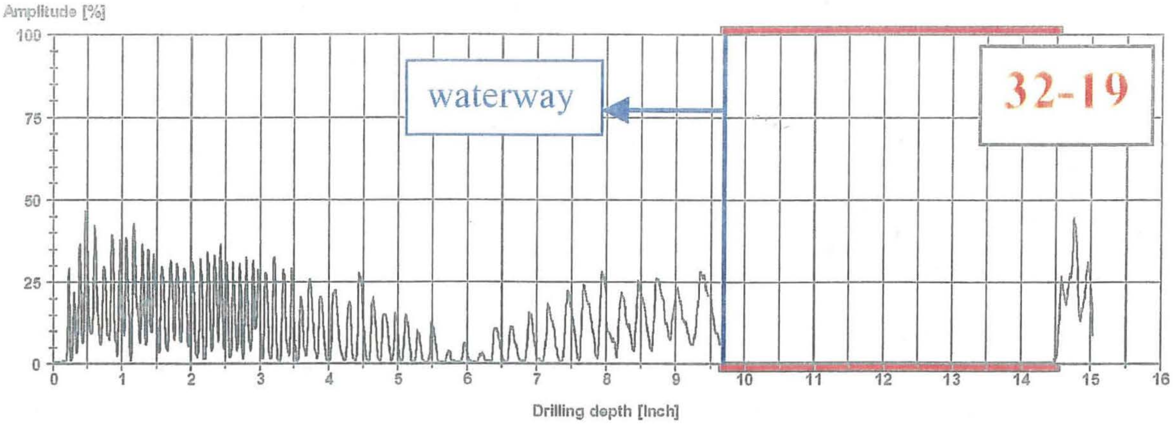
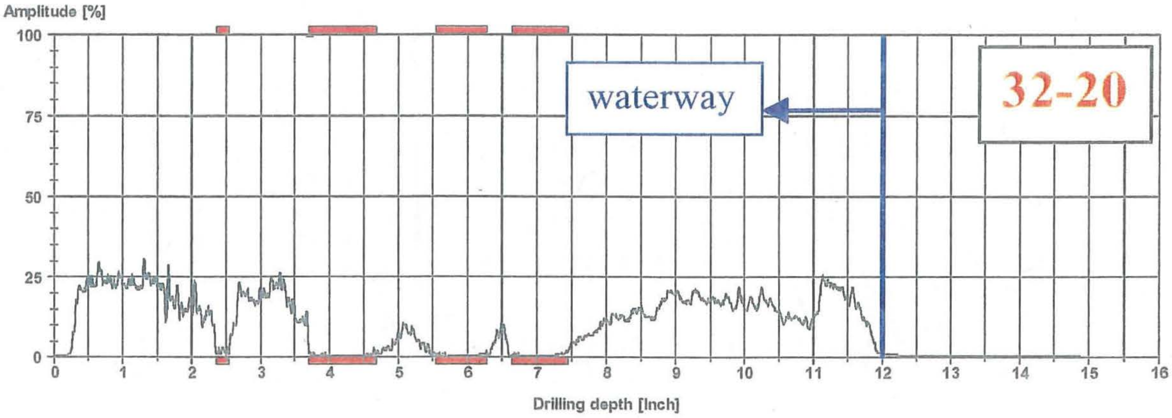
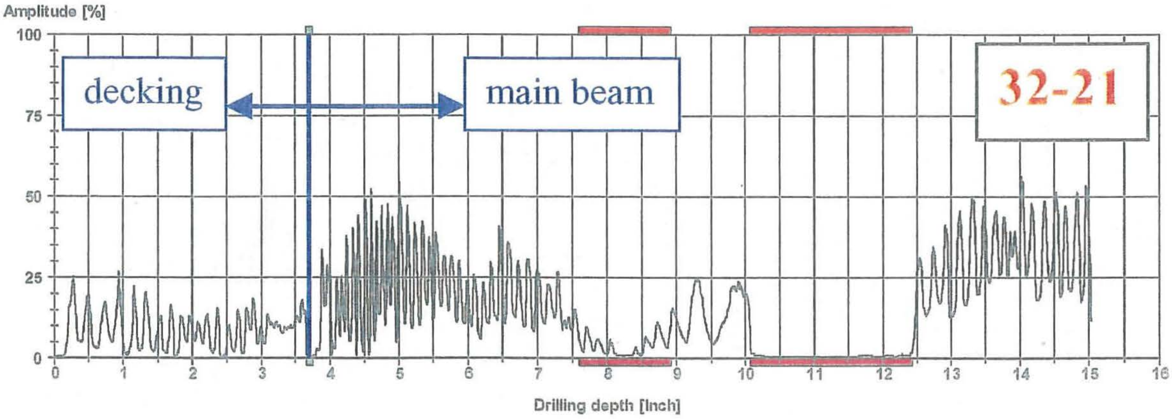
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
clamp
frame
32-16

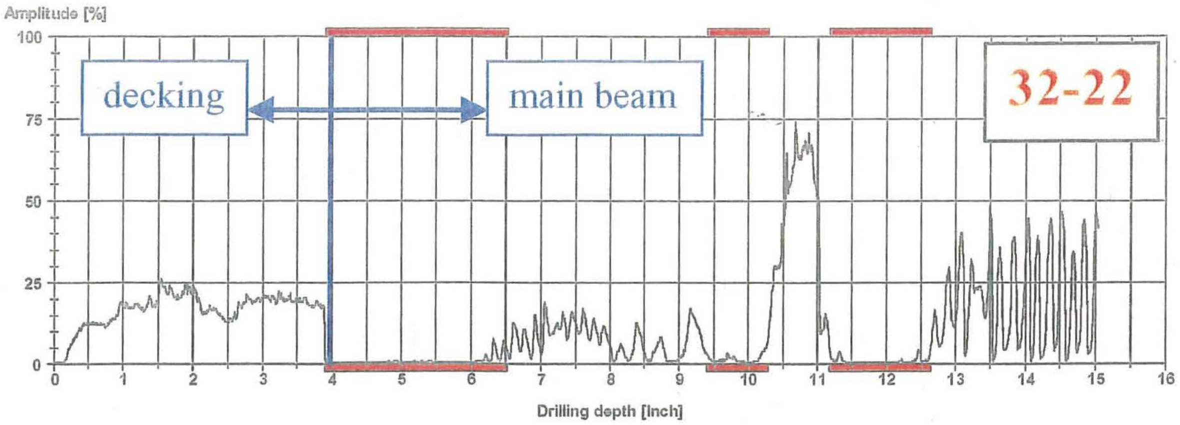

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
clamp
frame
32-17

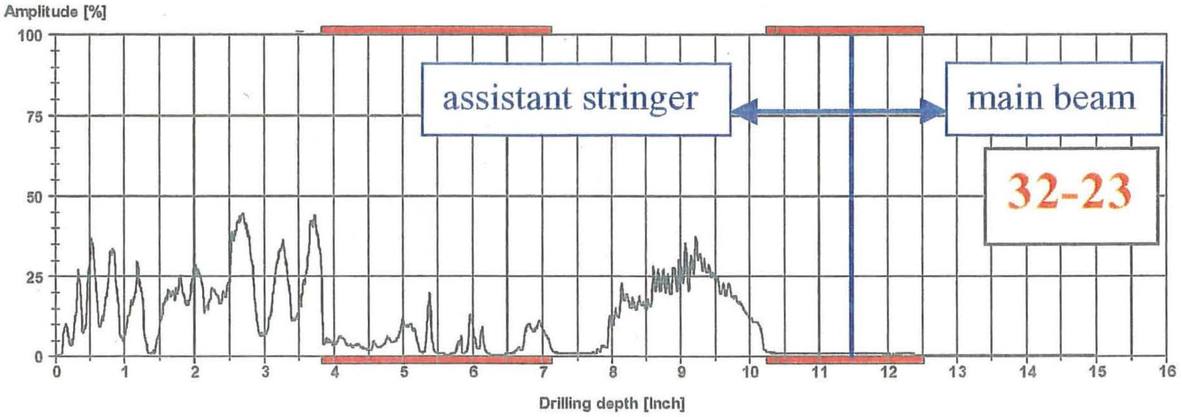

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
clamp
frame
32-18

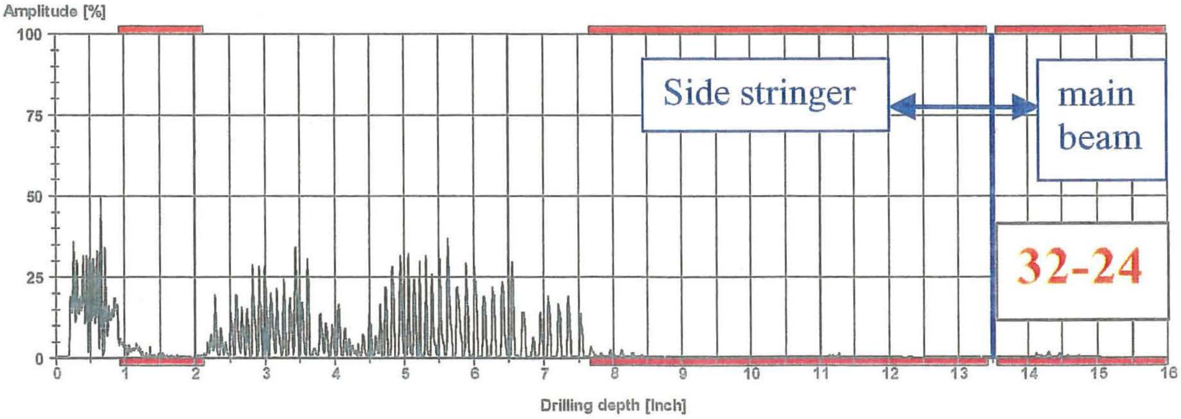

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
waterway
32-19

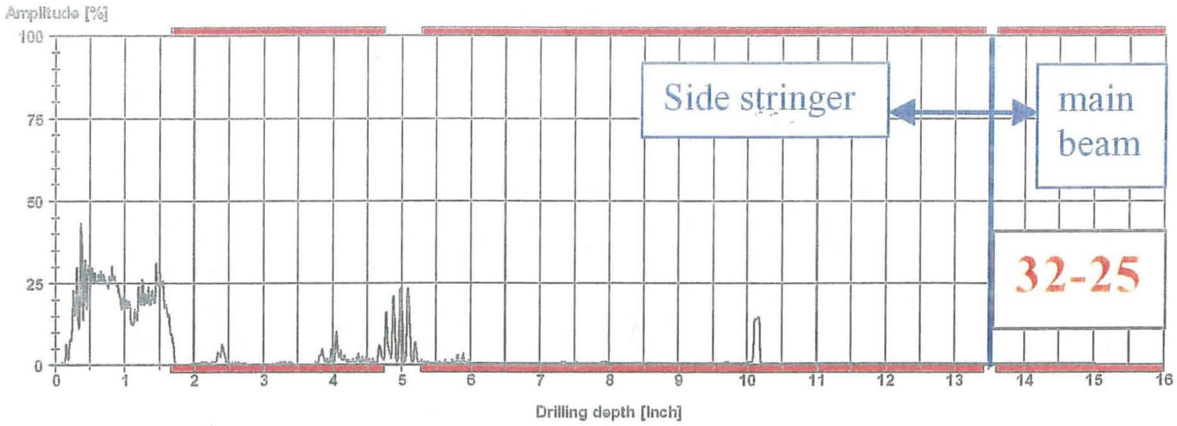

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
waterway
32-20

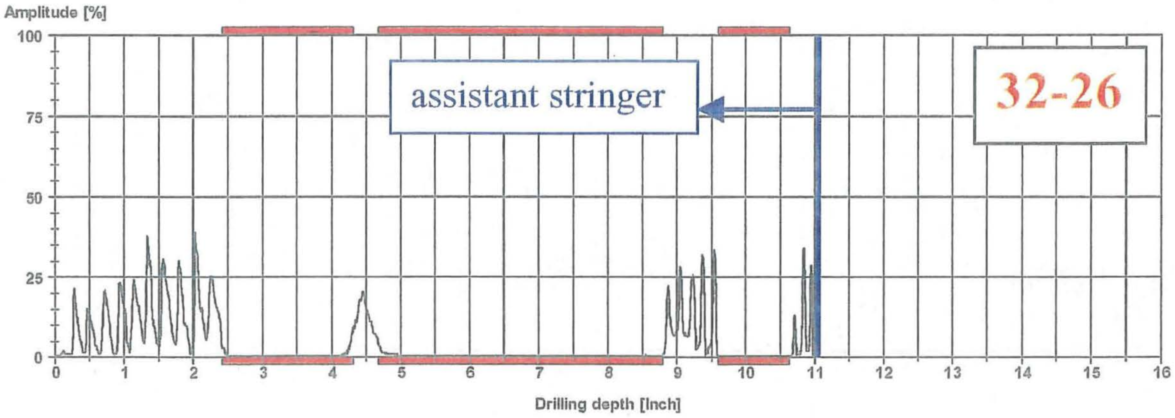

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
decking
main beam
32-21


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
decking
main beam
32-22


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
assistant stringer
main beam
32-23


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
Side stringer
main beam
32-24


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
Side stringer
main beam
32-25


Amplitude [%]
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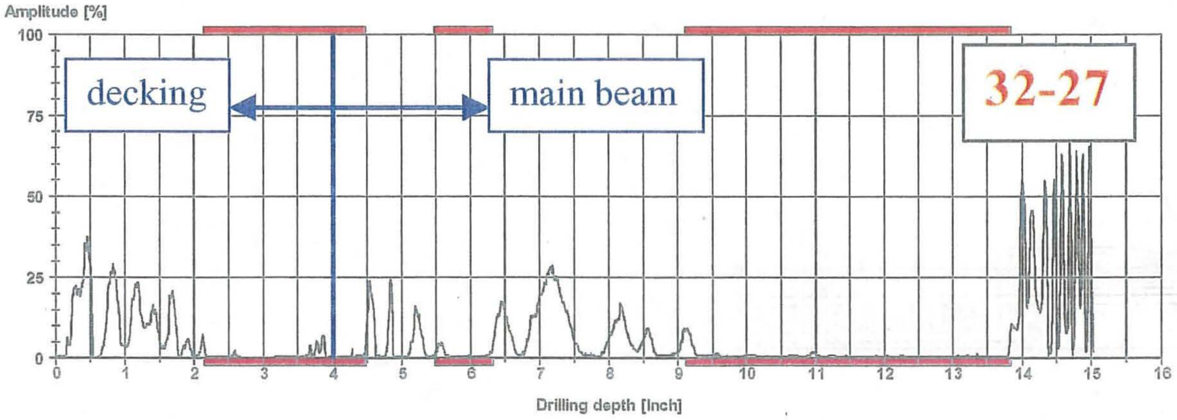
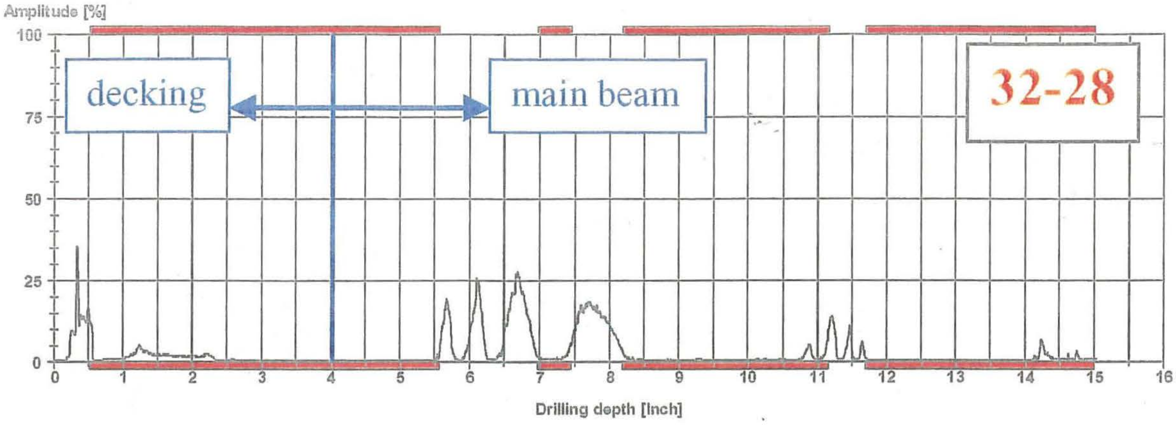
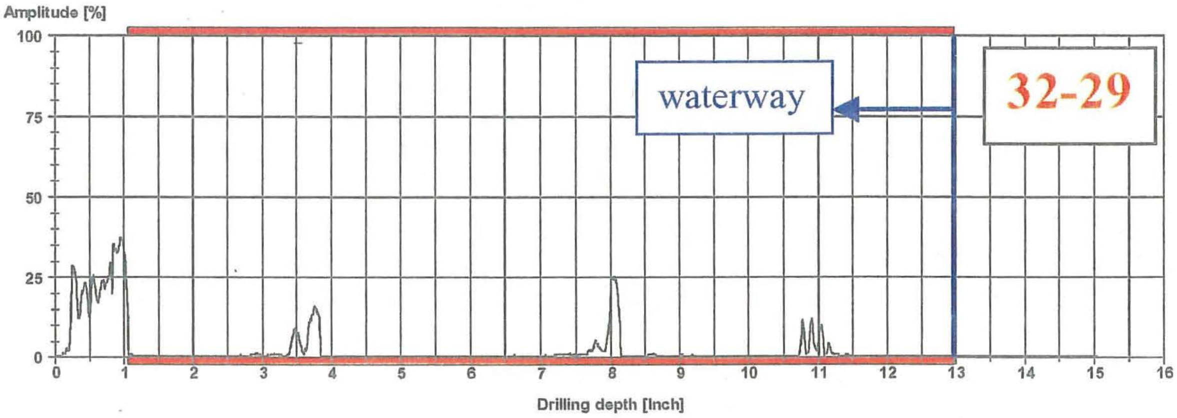
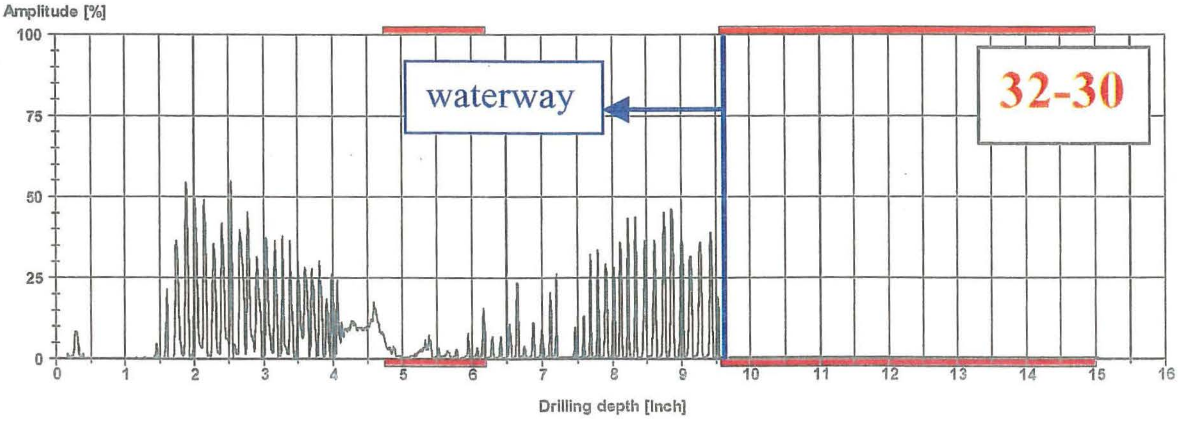
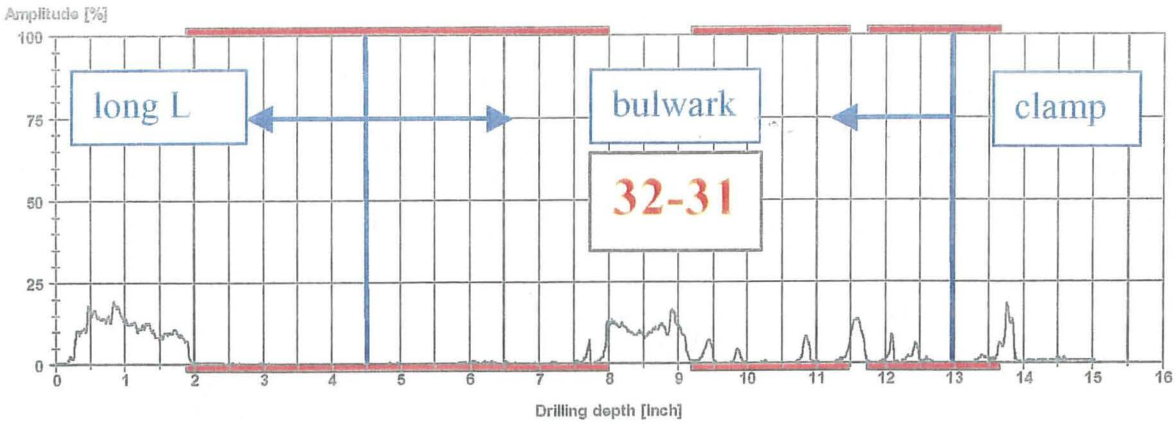
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
assistant stringer
32-26

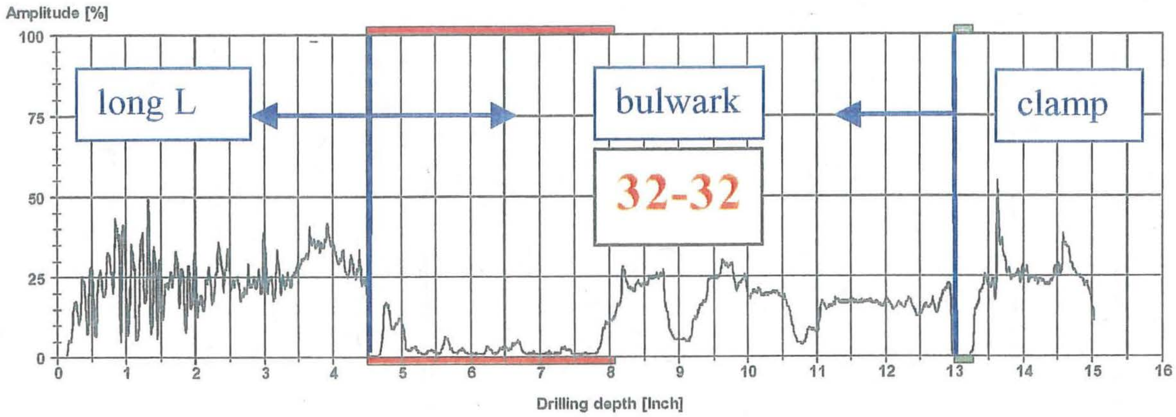

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
decking
main beam
32-27

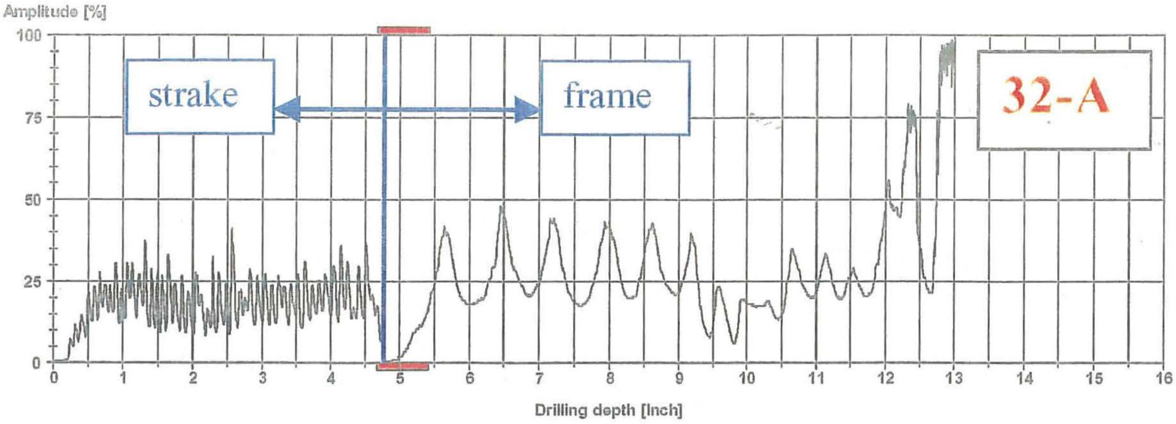

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
decking
main beam
32-28

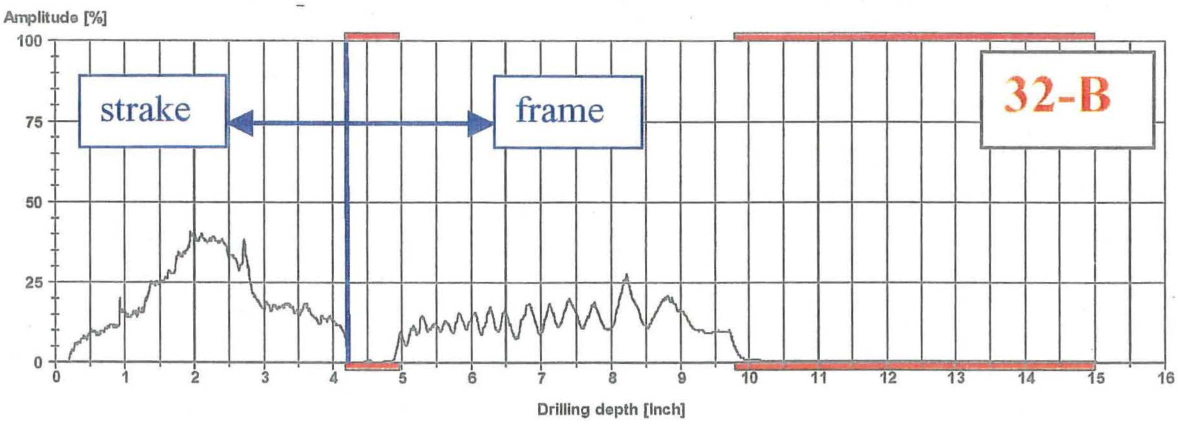

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
waterway
32-29

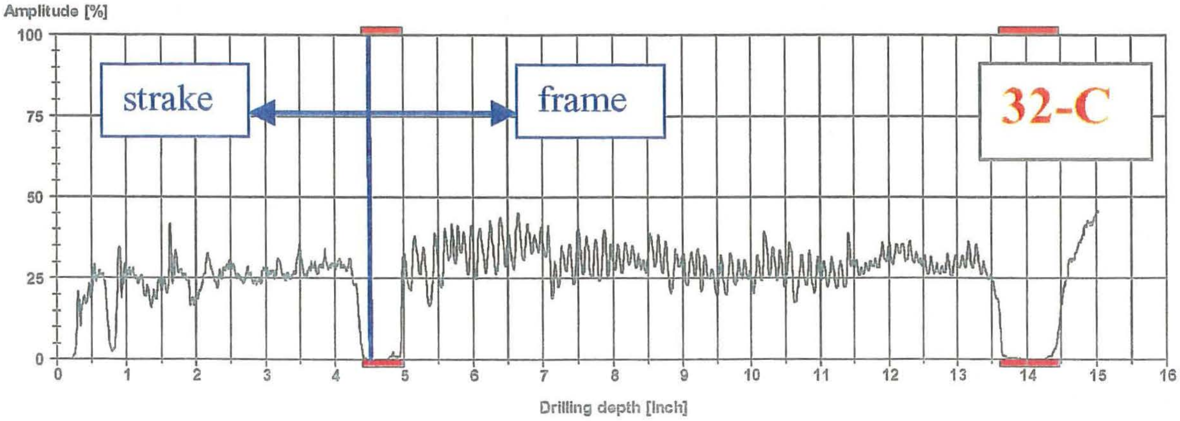

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
waterway
32-30


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
long L
bulwark
clamp
32-31
Drilling depth [inch]


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
long L
bulwark
clamp
32-32
Drilling depth [inch]


Amplitude [%]
100
75
50
25
0
strake
frame
32-A
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]


Amplitude [%]
100
75
50
25
0
strake
frame
32-B
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]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25
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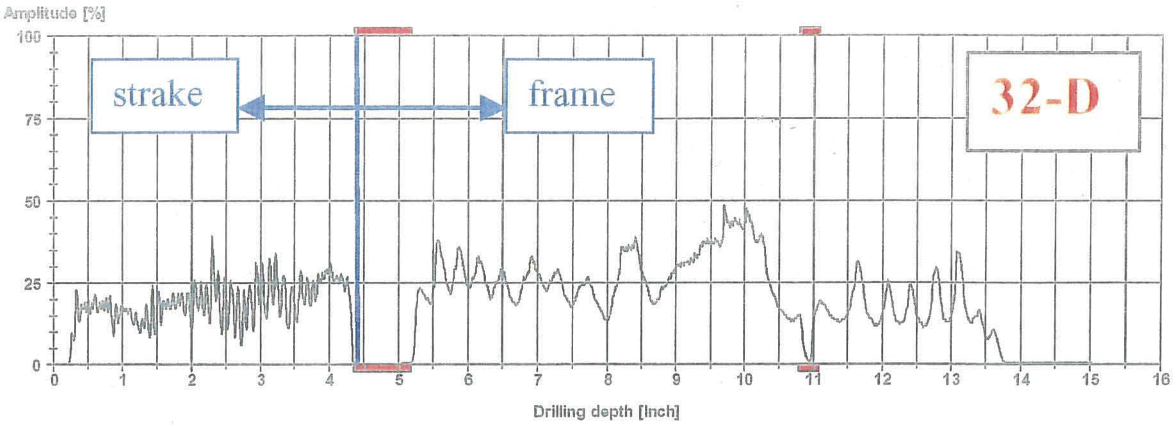
strake
frame
32-C
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]


Amplitude [%]
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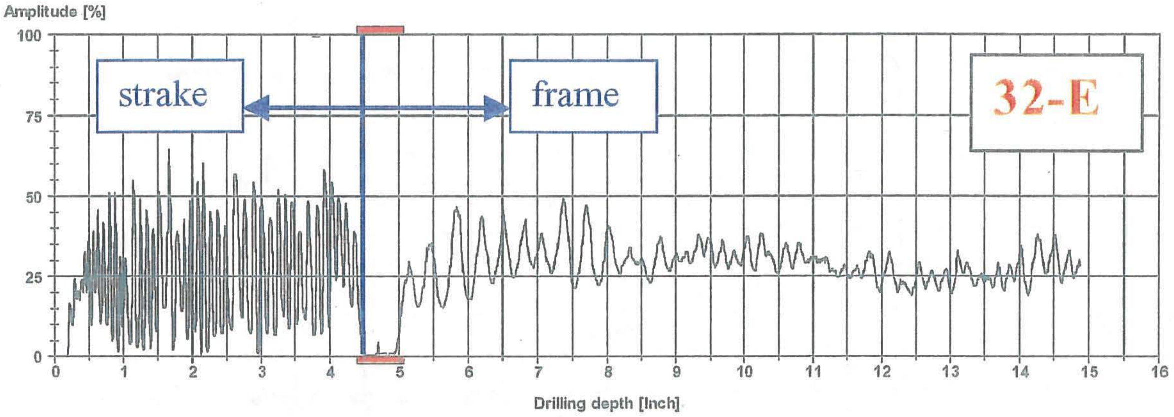
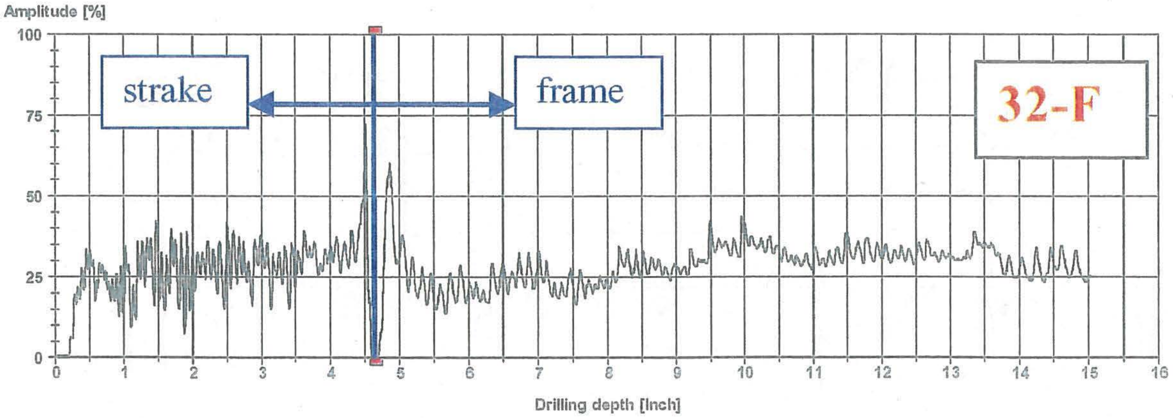
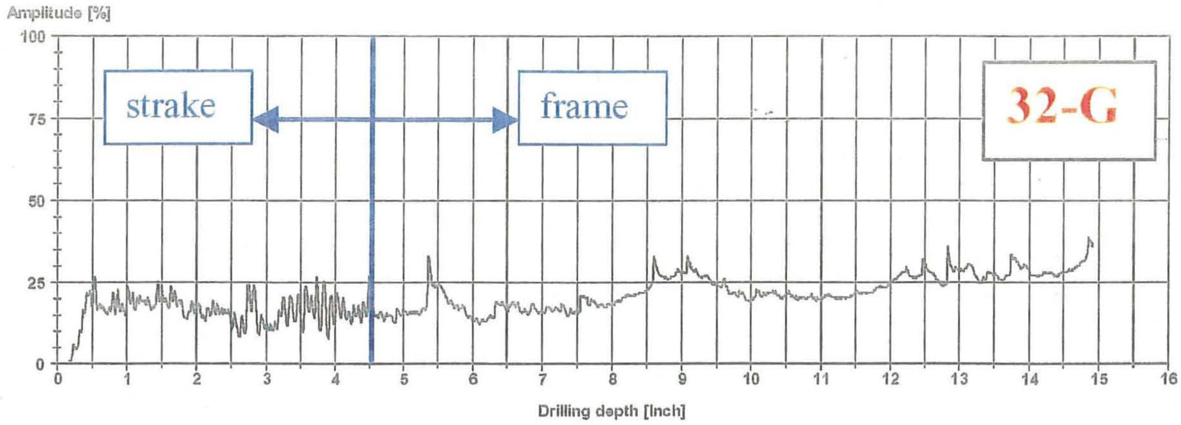
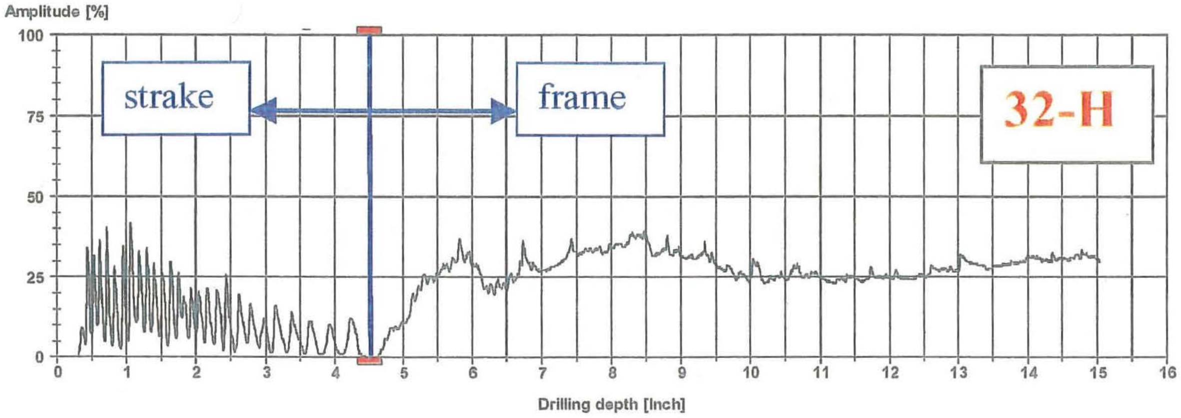
50
25
0
strake
frame
32-D
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]


Amplitude [%]
100
75
50
25
0
strake
frame
32-E
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]


Amplitude [%]
100
75
50
25
0
strake
frame
32-F
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

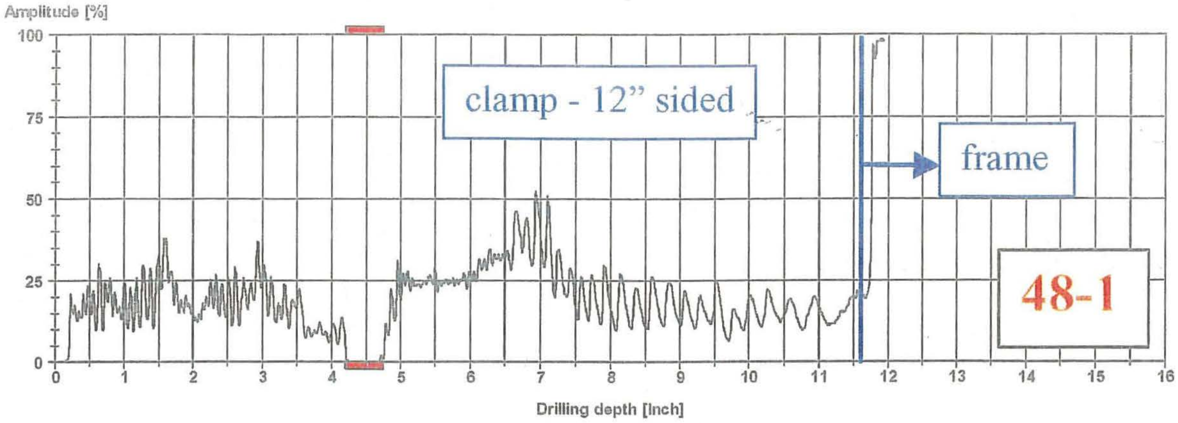

Amplitude [%]
100
75
50
25
0
strake
frame
32-G
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

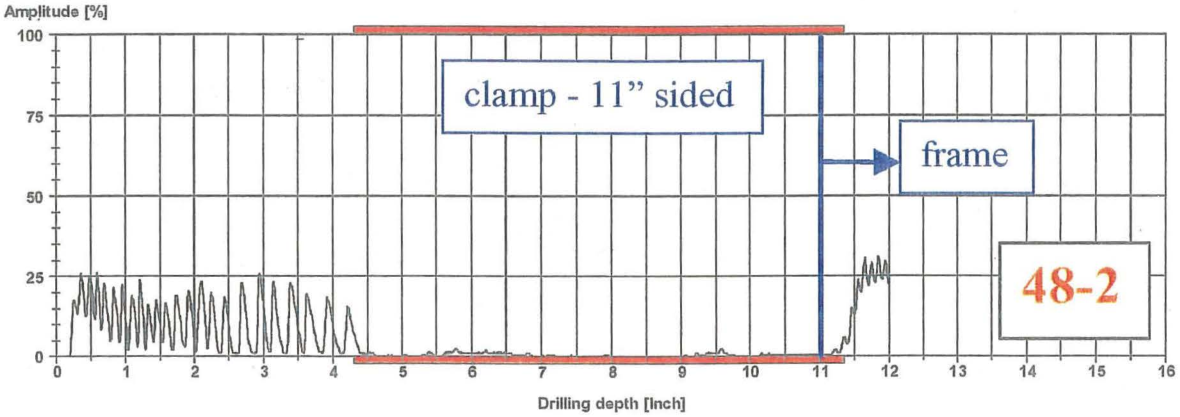

Amplitude [%]
100
75
50
25
0
strake
frame
32-H
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

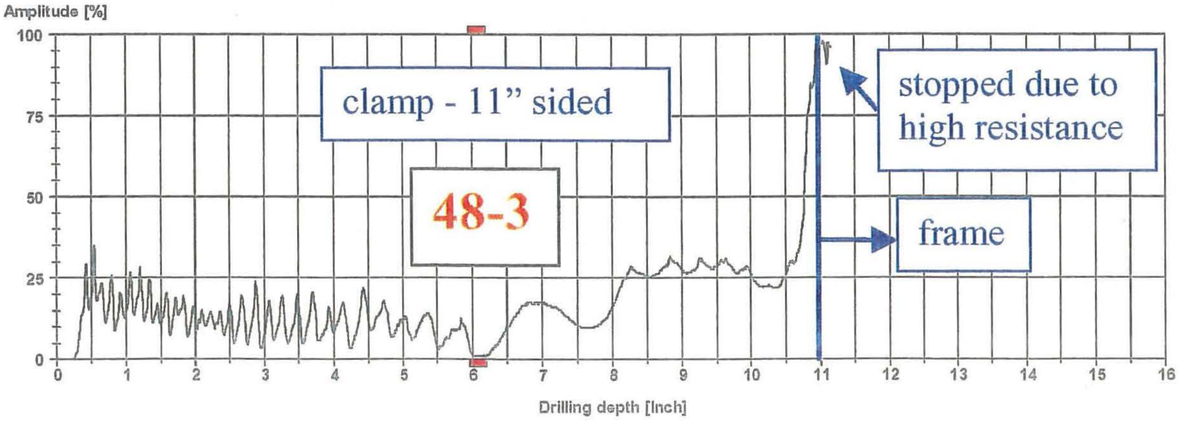
Appendix C5

Resistance Micro-drilling Plots

Hull Frame #48


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
clamp - 12" sided
frame
48-1


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
clamp - 11" sided
frame
48-2


Amplitude [%]
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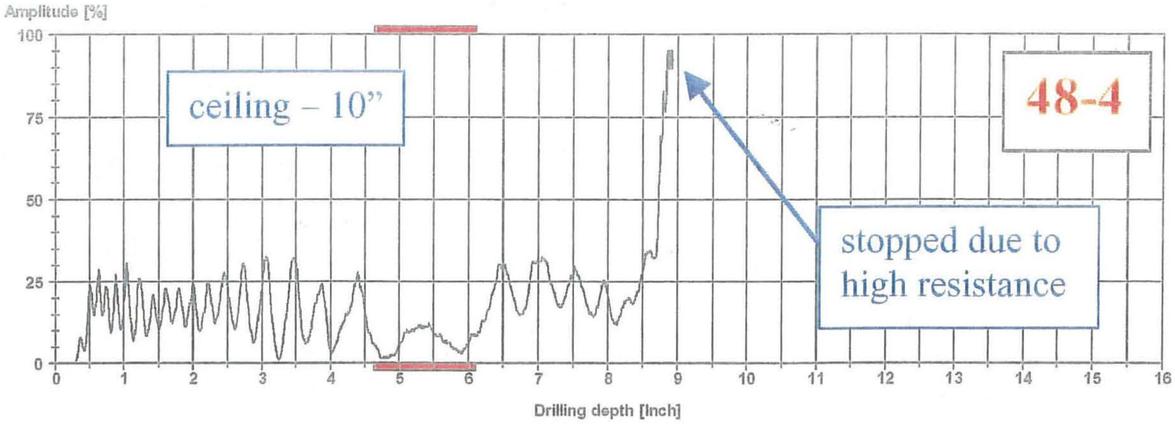
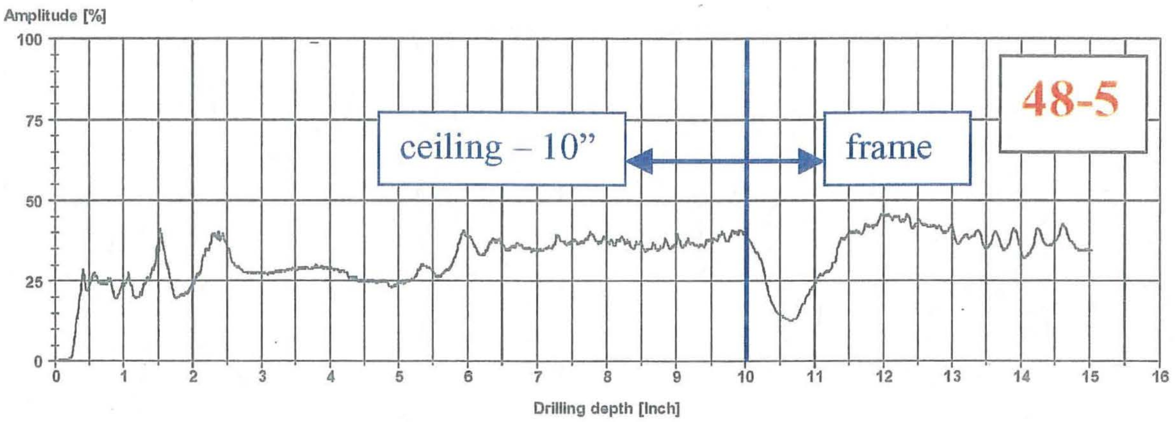
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
clamp - 11" sided
48-3
stopped due to high resistance
frame


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
ceiling – 10"
48-4
stopped due to high resistance


Amplitude [%]
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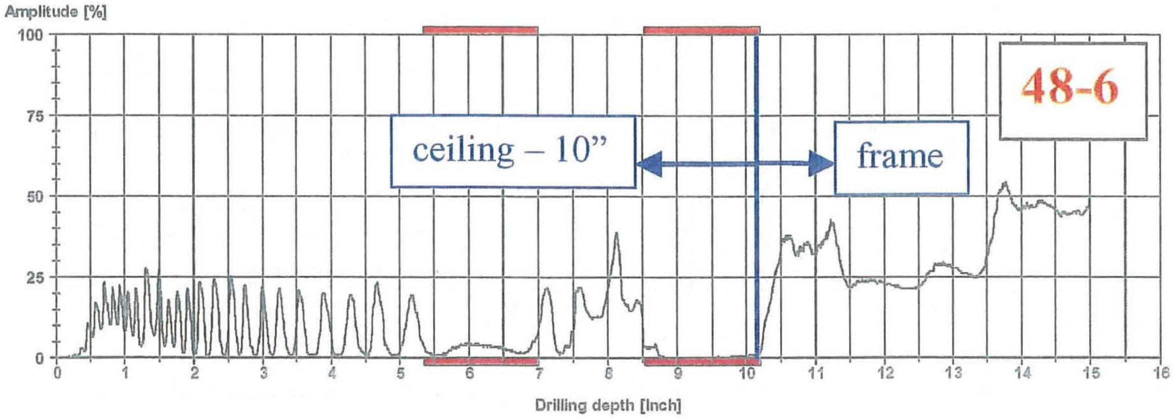
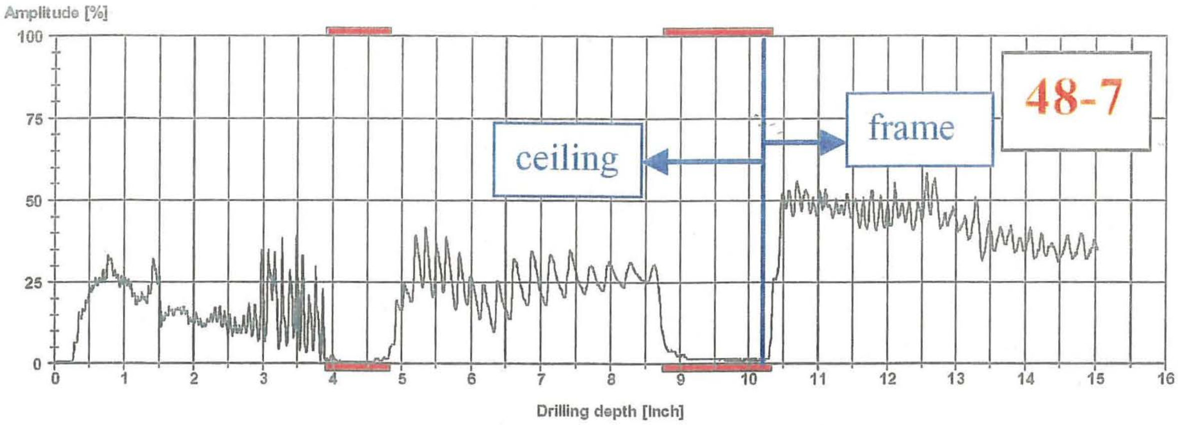
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
ceiling – 10"
frame
48-5


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
ceiling – 10"
frame
48-6


Amplitude [%]
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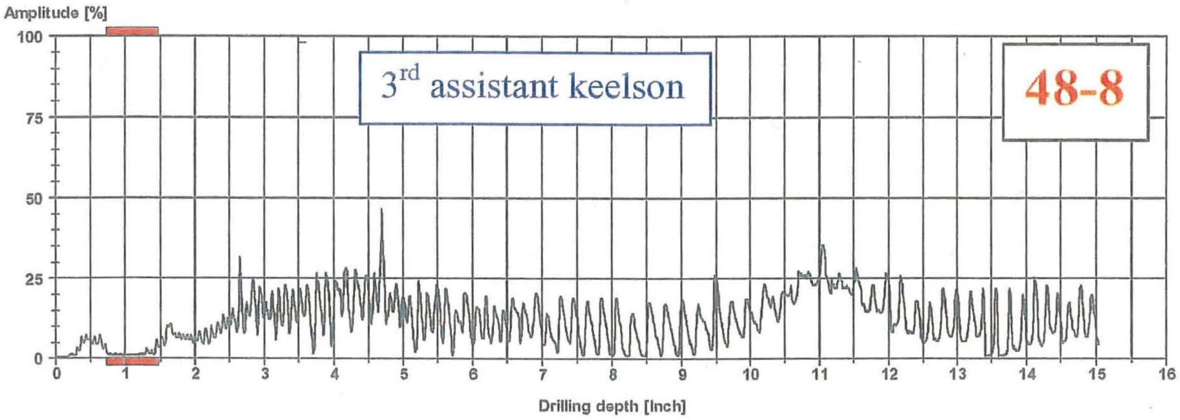
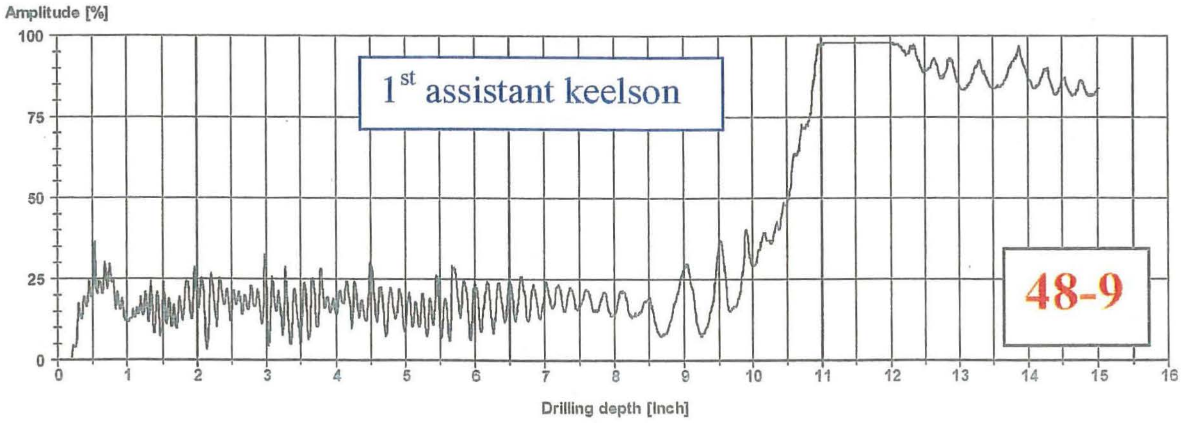
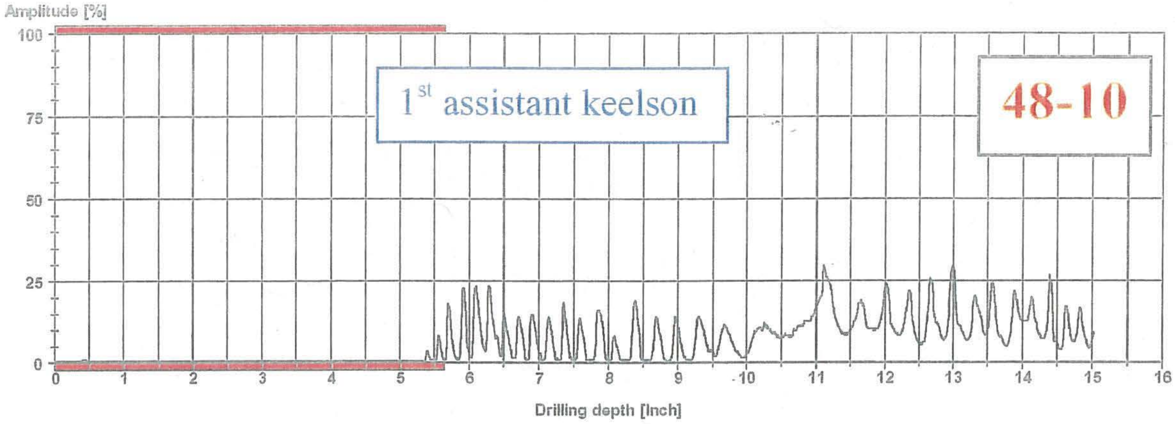
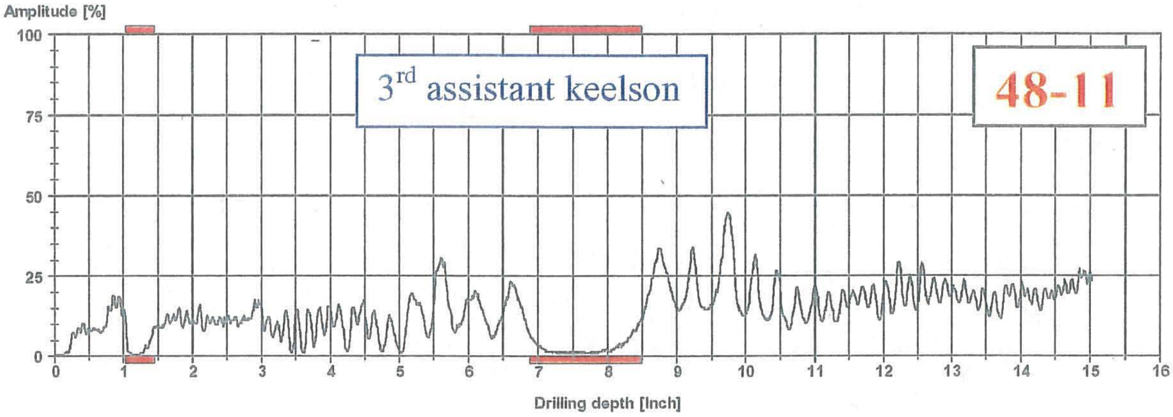
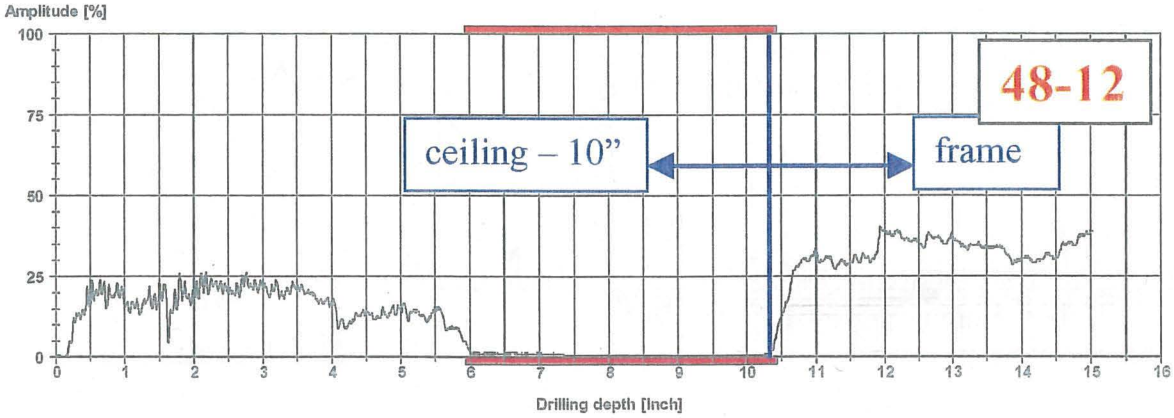
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
ceiling
frame
48-7

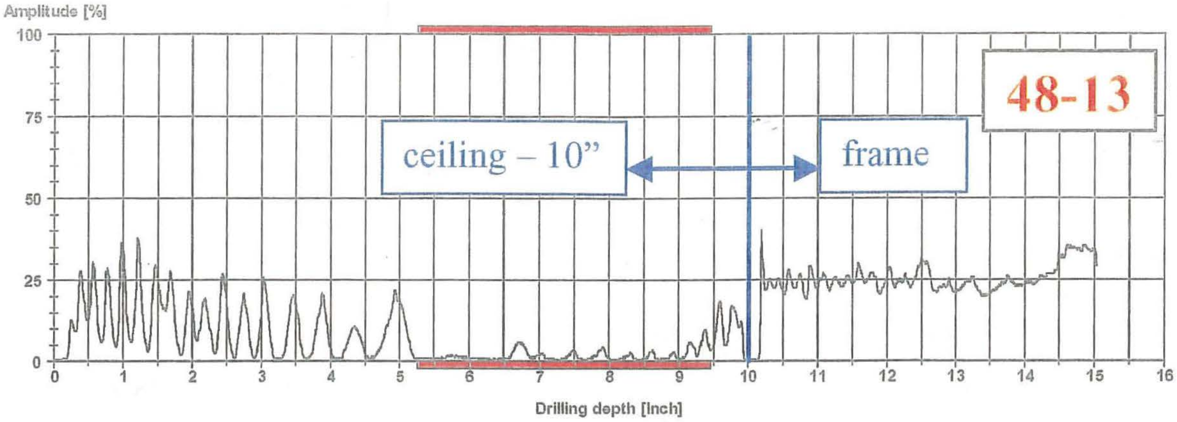

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
3rd assistant keelson
48-8

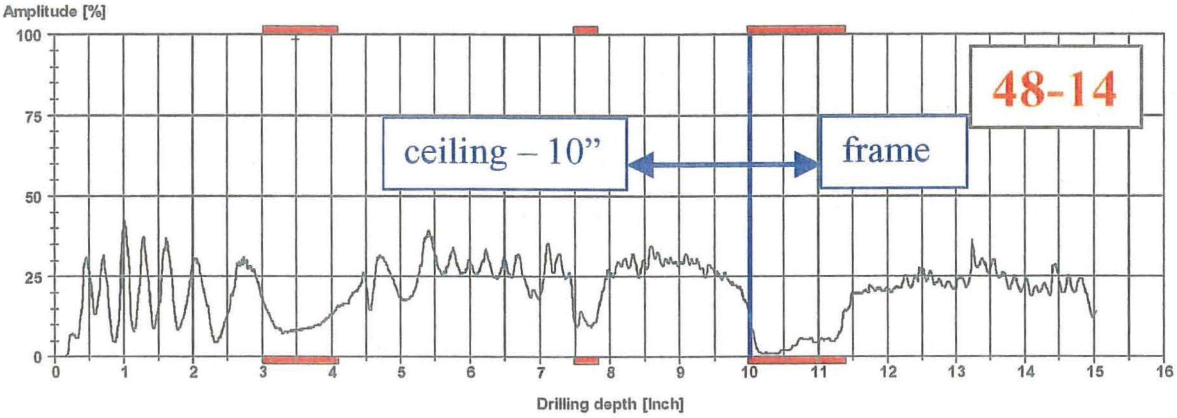

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
1st assistant keelson
48-9

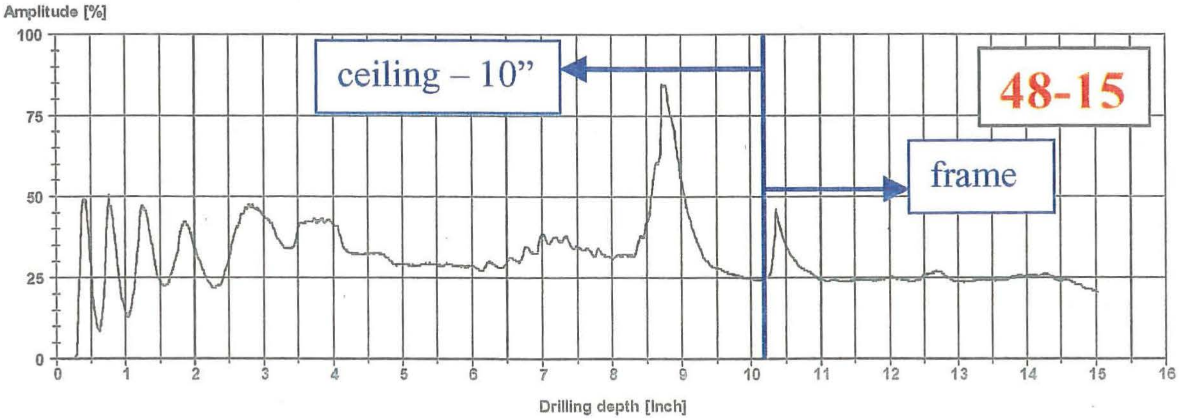

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
1st assistant keelson
48-10

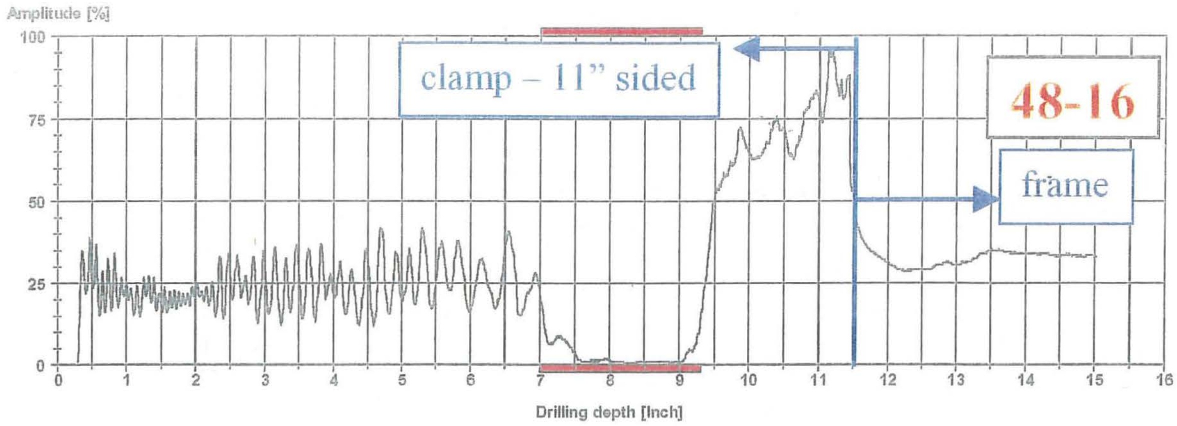

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
3rd assistant keelson
48-11

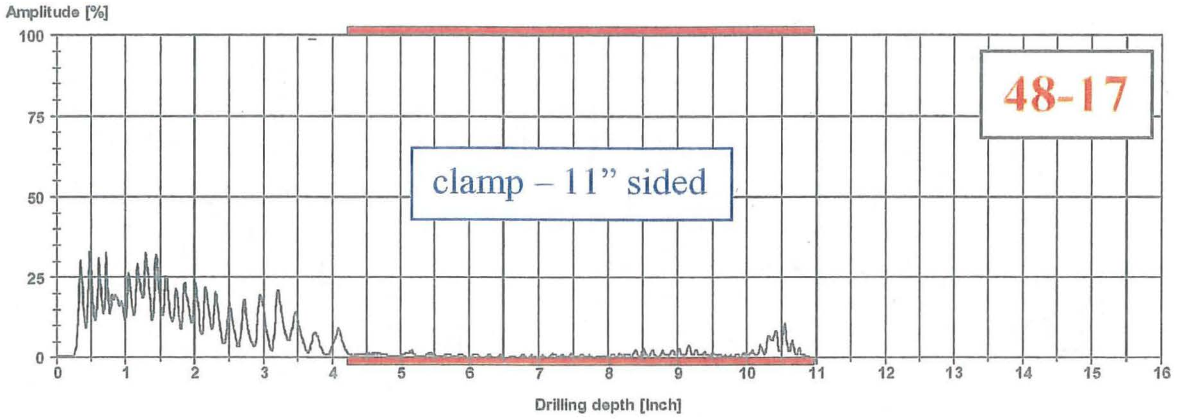

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
48-12
ceiling – 10"
frame


Amplitude [%]
100
75
50
25
0
48-13
ceiling – 10"
frame
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]


Amplitude [%]
100
75
50
25
0
48-14
ceiling – 10"
frame
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]


Amplitude [%]
100
75
50
25
0
ceiling – 10"
48-15
frame
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]


Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
clamp – 11" sided
48-16
frame


Amplitude [%]
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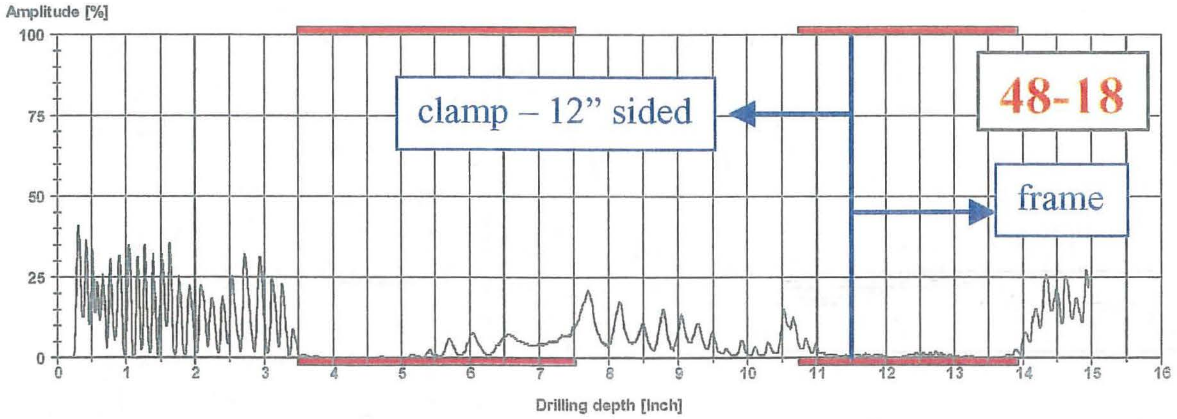
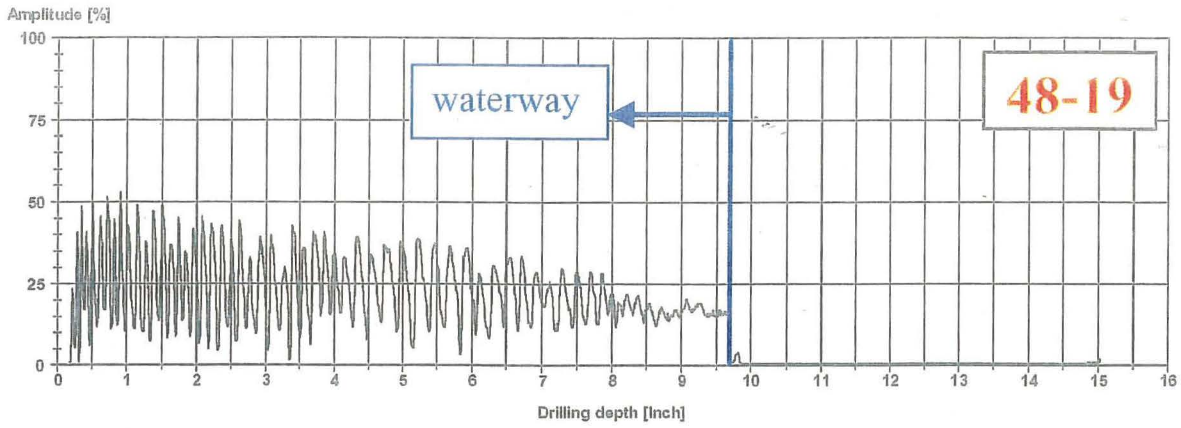
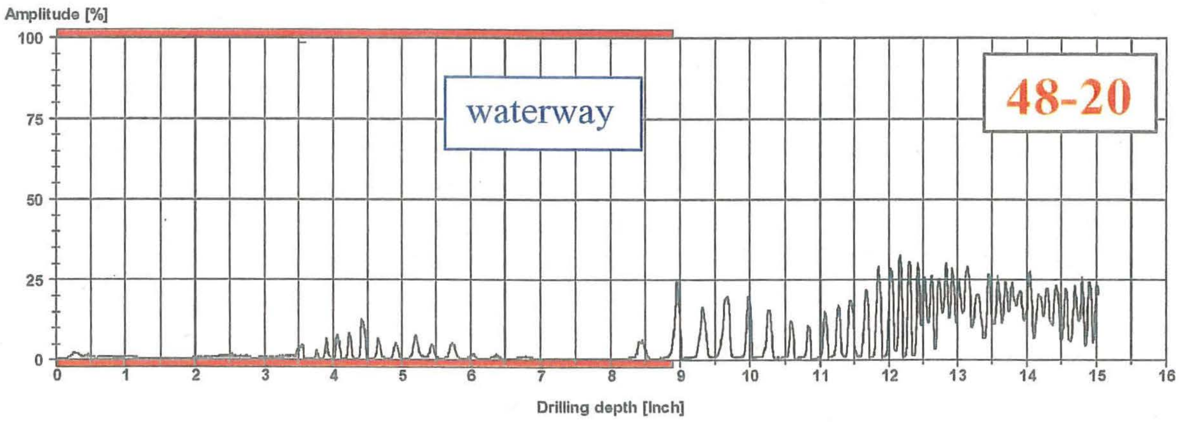
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
48-17
clamp – 11" sided


Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
clamp – 12" sided
48-18
frame


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
waterway
48-19


Amplitude [%]
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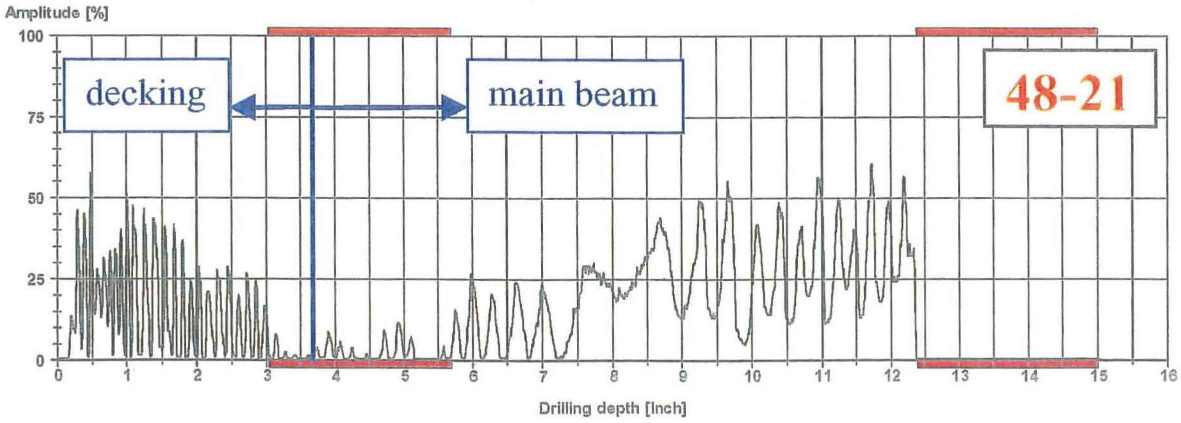
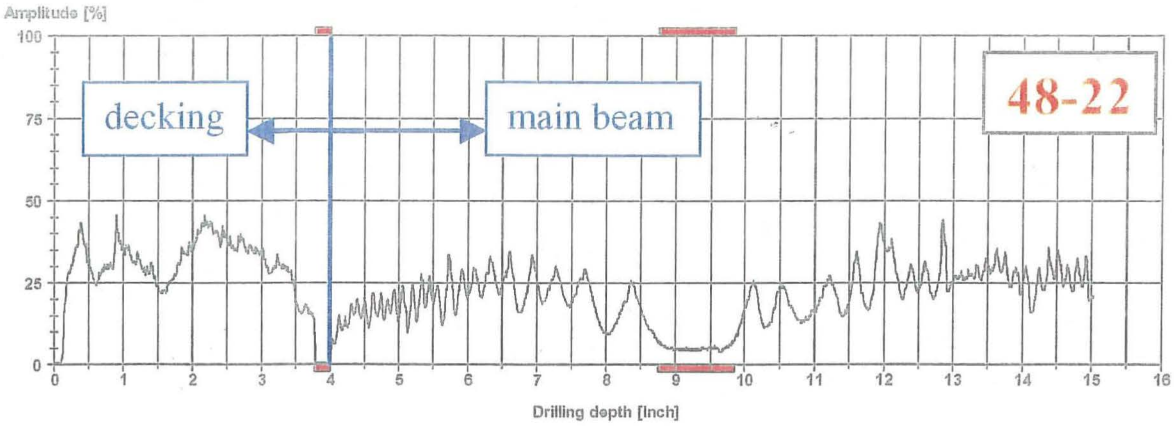
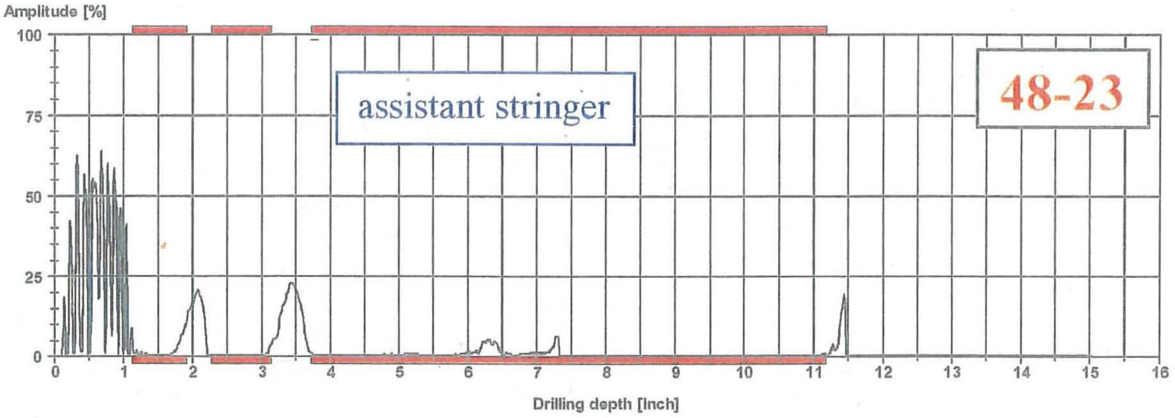
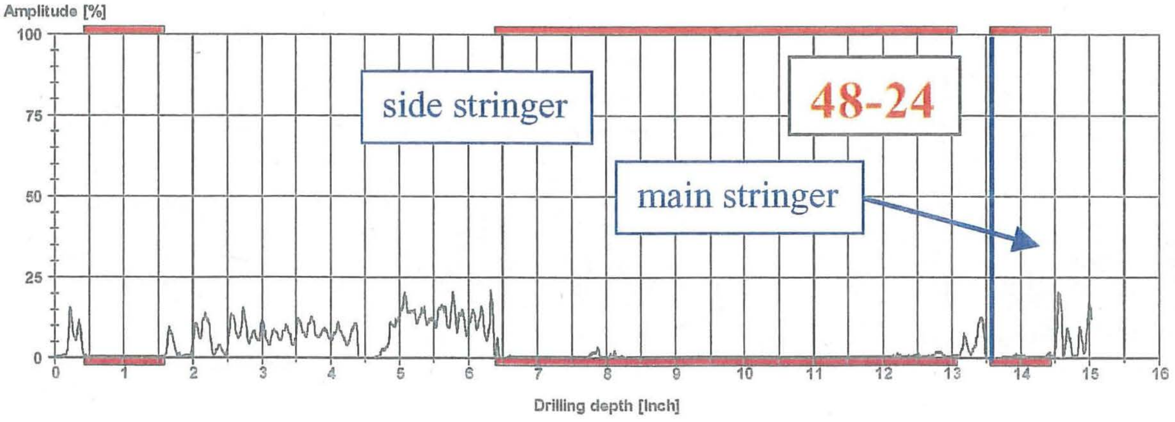
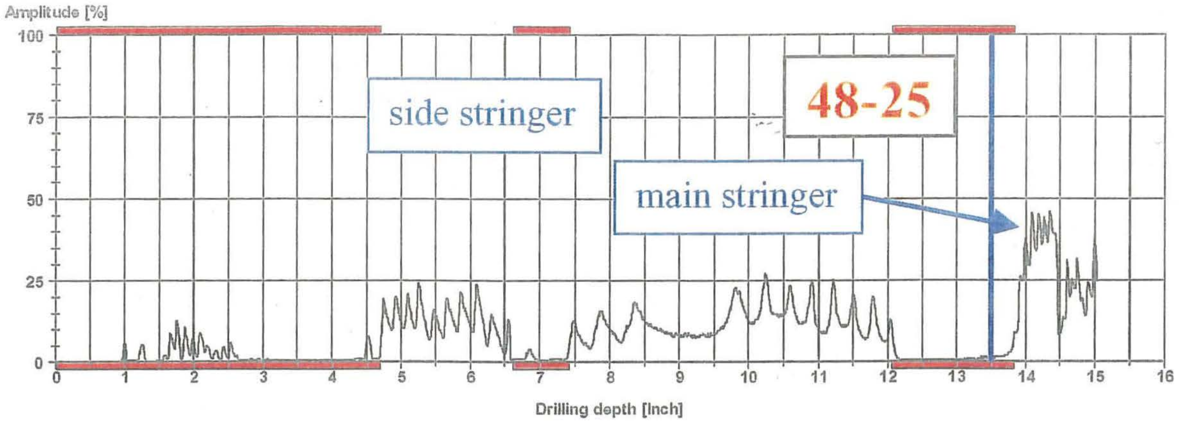
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
waterway
48-20

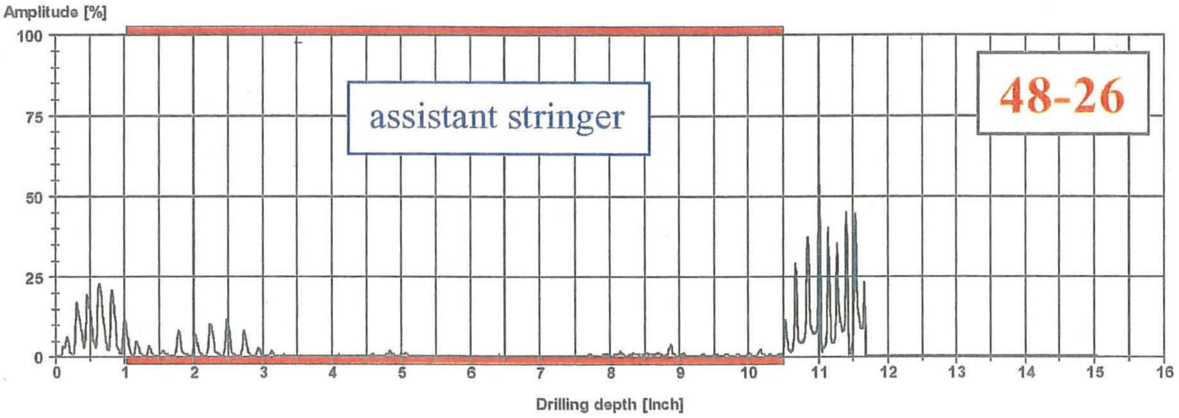

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
decking
main beam
48-21


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
decking
main beam
48-22


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
assistant stringer
48-23


Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
side stringer
48-24
main stringer


Amplitude [%]
100
75
50
25
0
side stringer
48-25
main stringer
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]


Amplitude [%]
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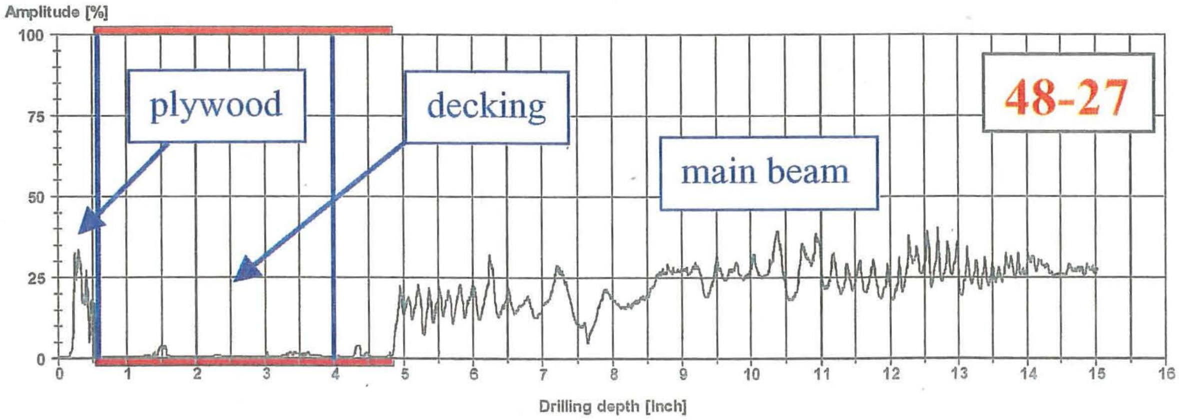
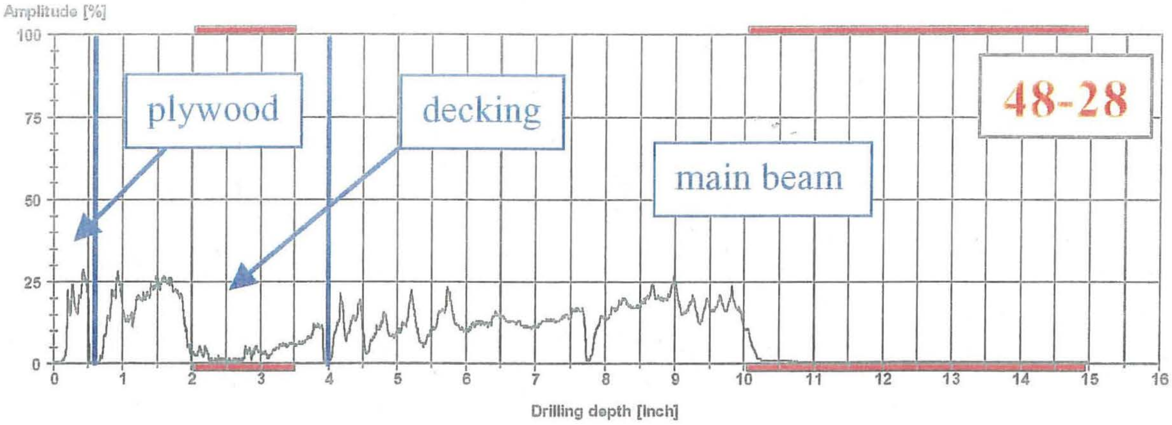
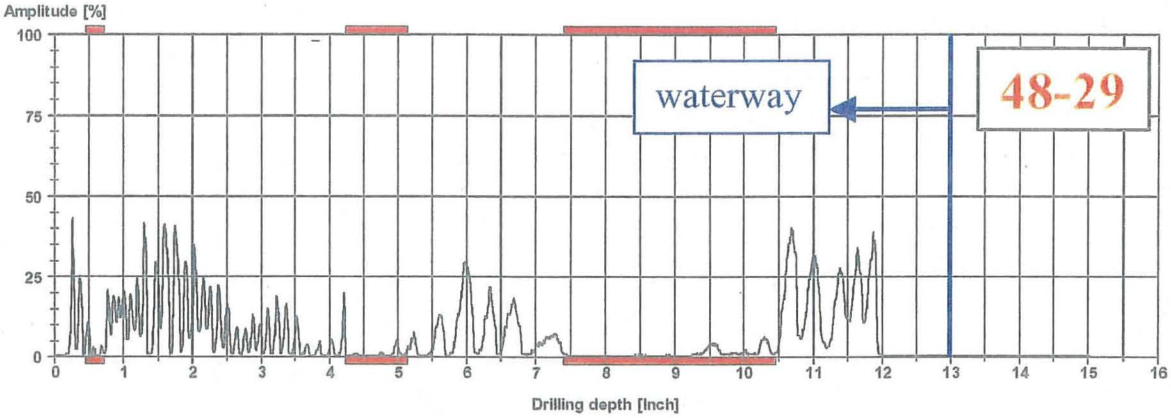
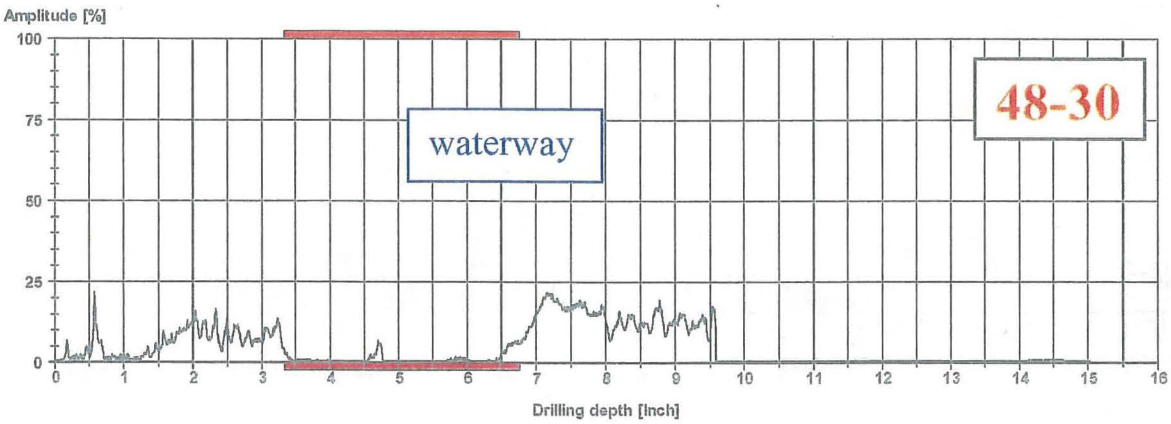
75
50
25
0
assistant stringer
48-26
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]


Amplitude [%]
100
75
50
25
0
plywood
decking
main beam
48-27
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]


Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
plywood
decking
main beam
48-28


Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
waterway
48-29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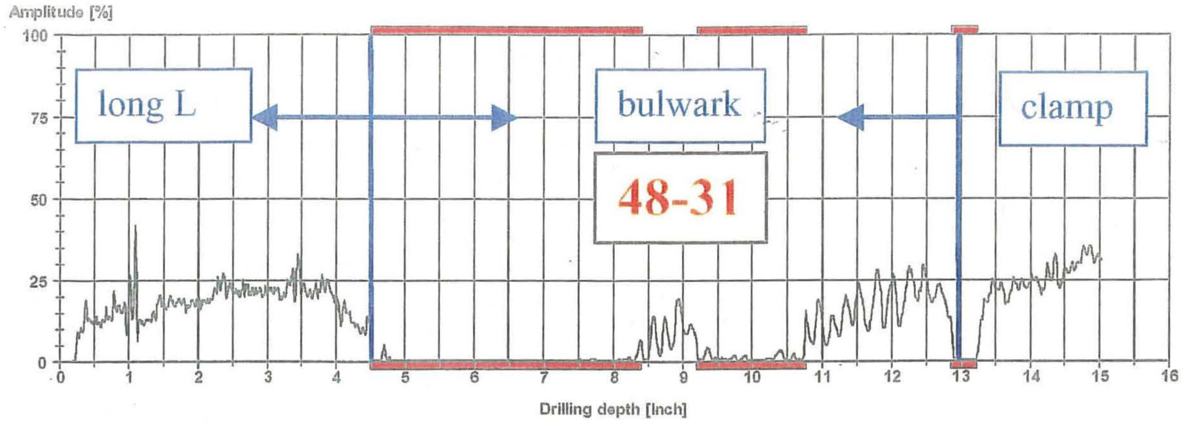
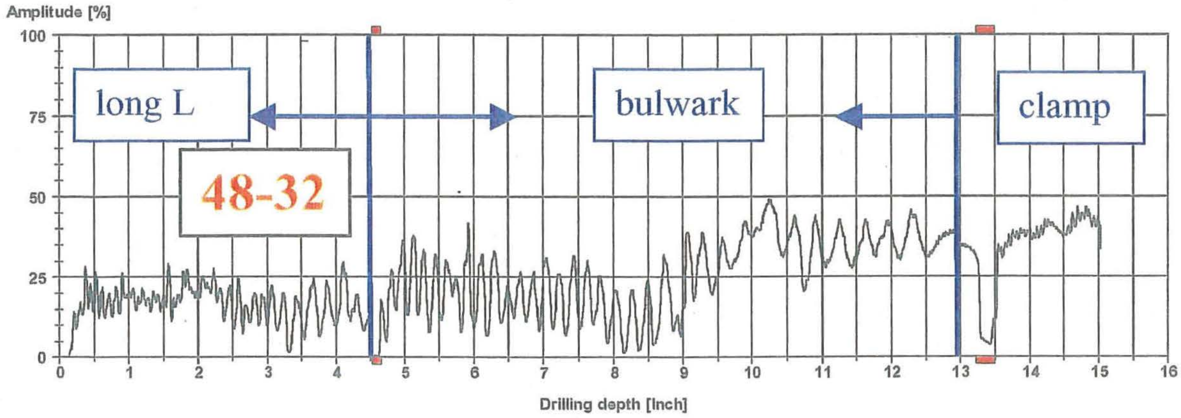
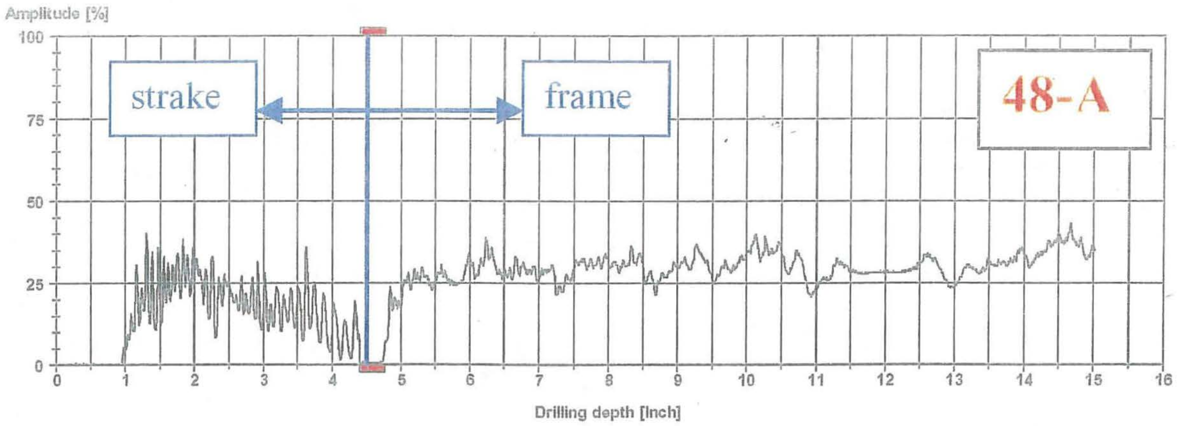
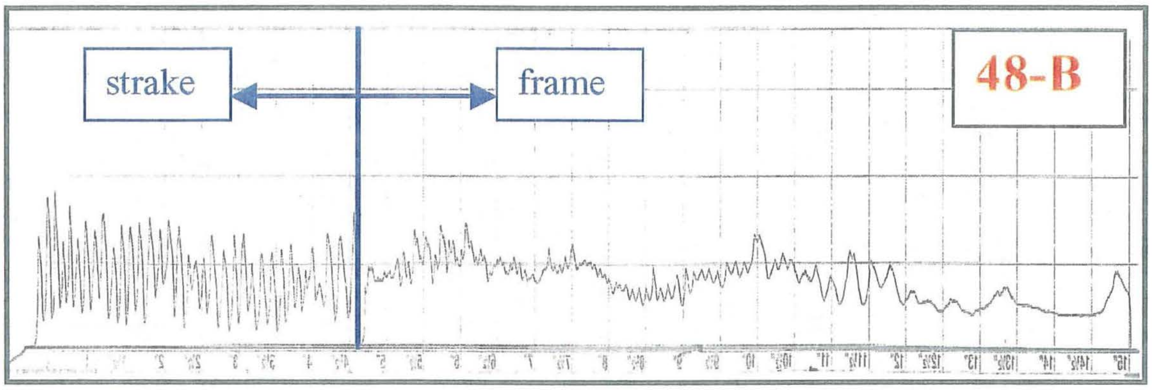
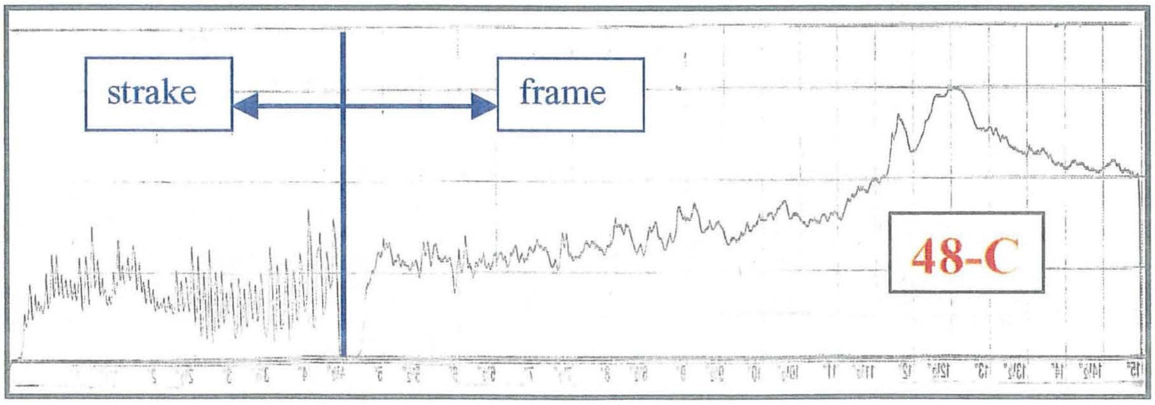
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
waterway
48-30

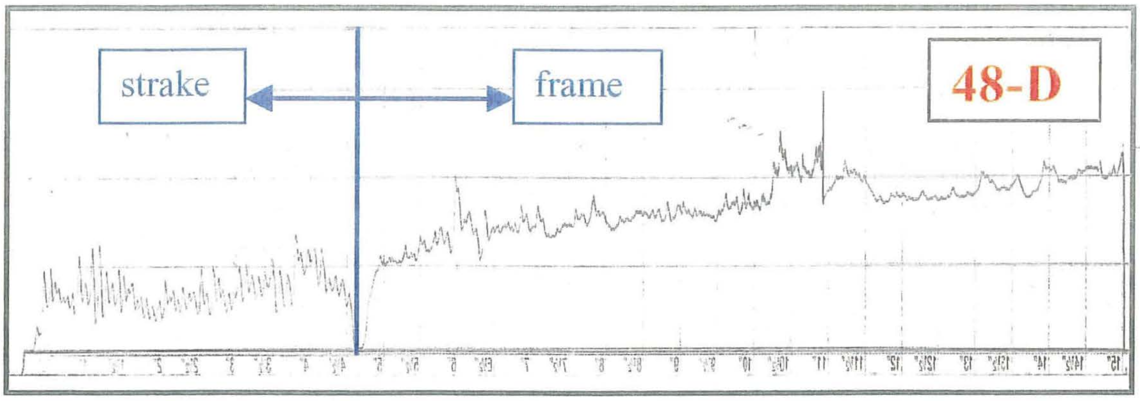

Amplitude [%]
100
75
50
25
0
long L
bulwark
clamp
48-31
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]

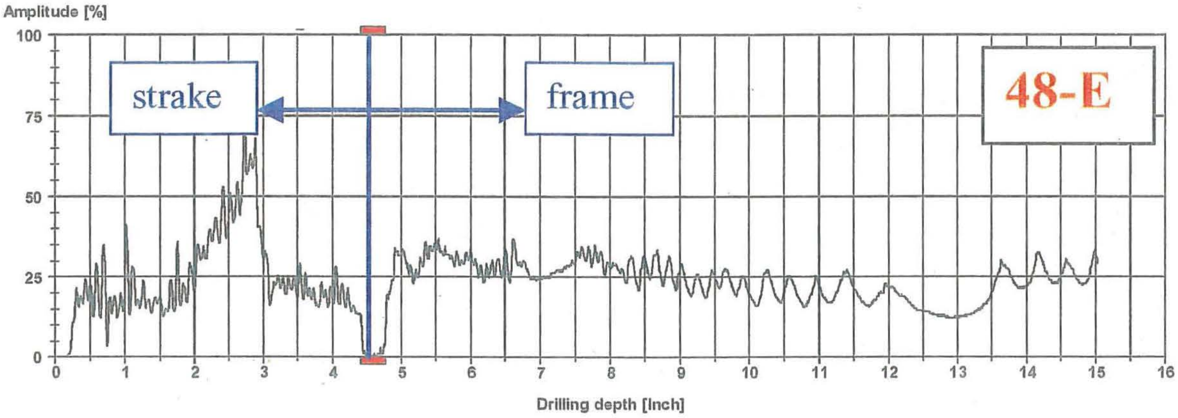

Amplitude [%]
100
75
50
25
0
long L
bulwark
clamp
48-32
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]

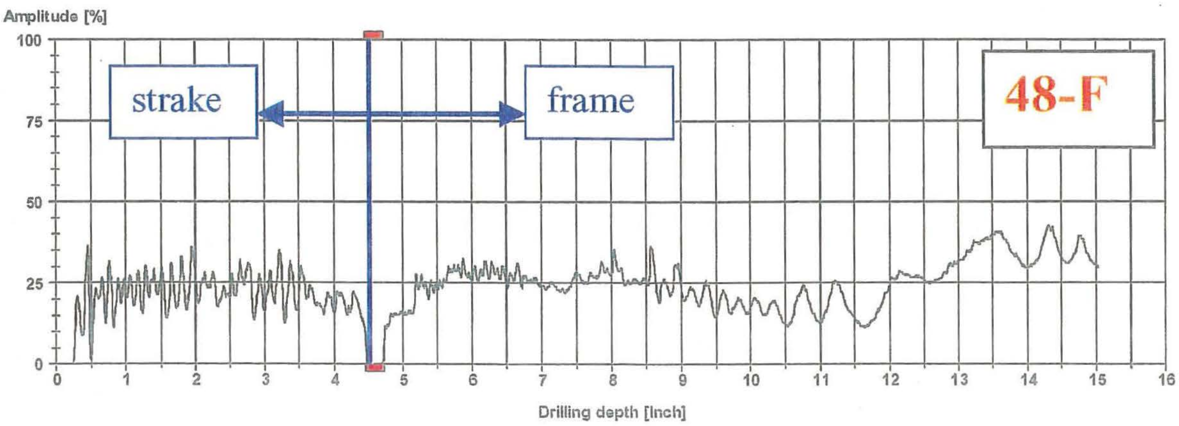

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
strake
frame
48-A

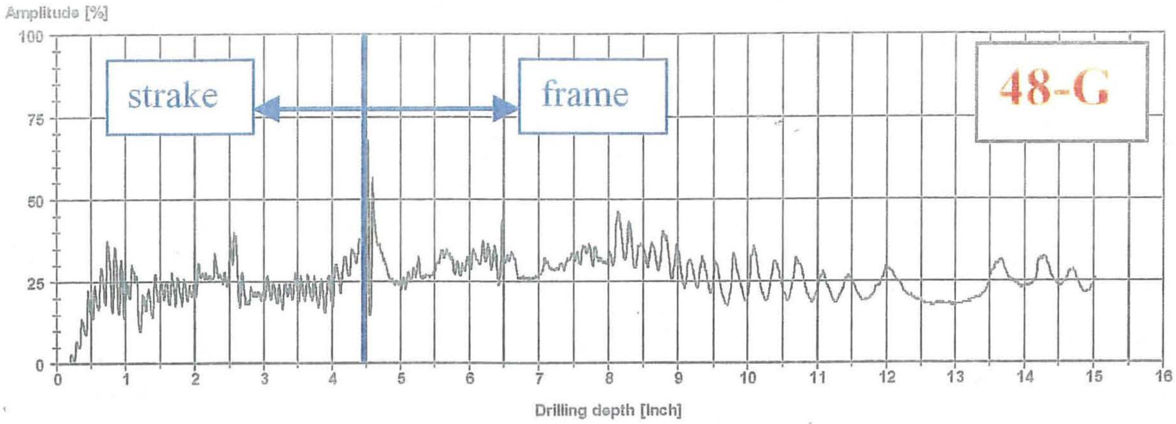

strake
frame
48-B

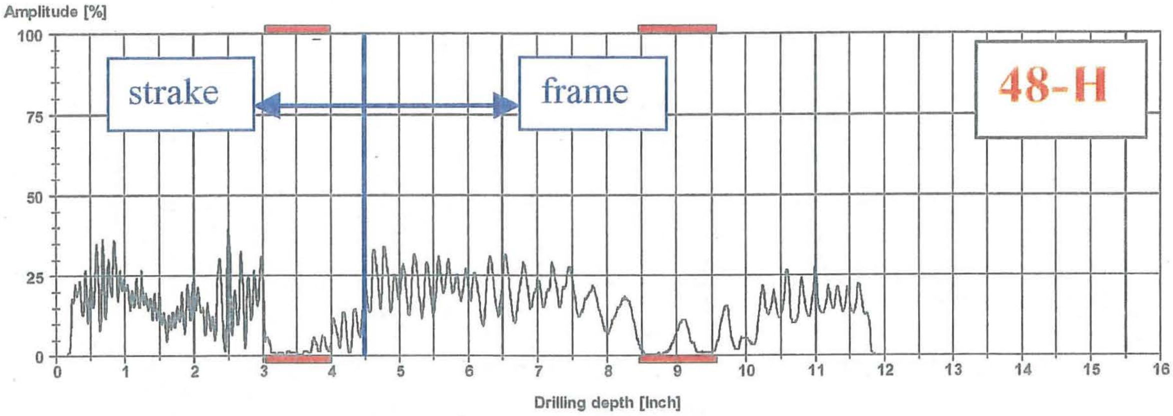

strake
frame
48-C


strake
frame
48-D


Amplitude [%]
100
75
50
25
0
strake
frame
48-E
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]


Amplitude [%]
100
75
50
25
0
strake
frame
48-F
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]

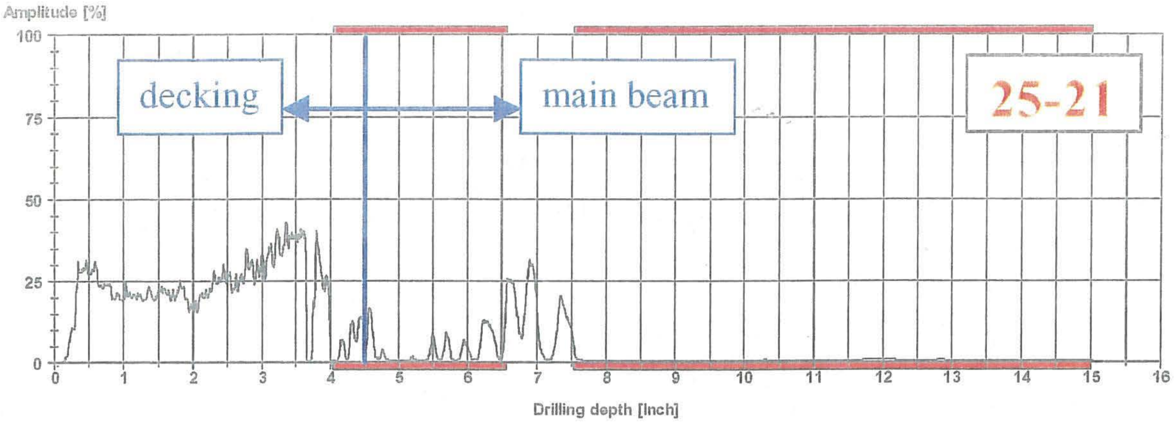

Amplitude [%]
100
75
50
25
0
strake
frame
48-G
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]

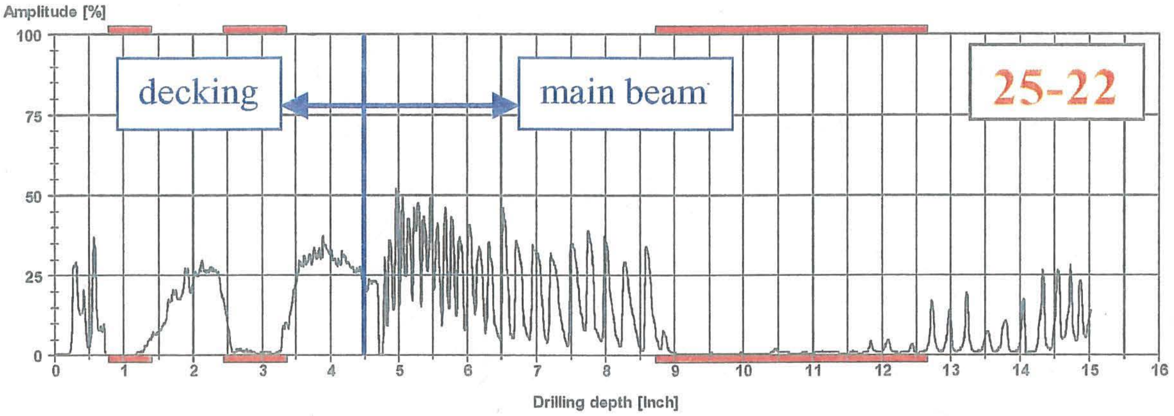

Amplitude [%]
100
75
50
25
0
strake
frame
48-H
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]

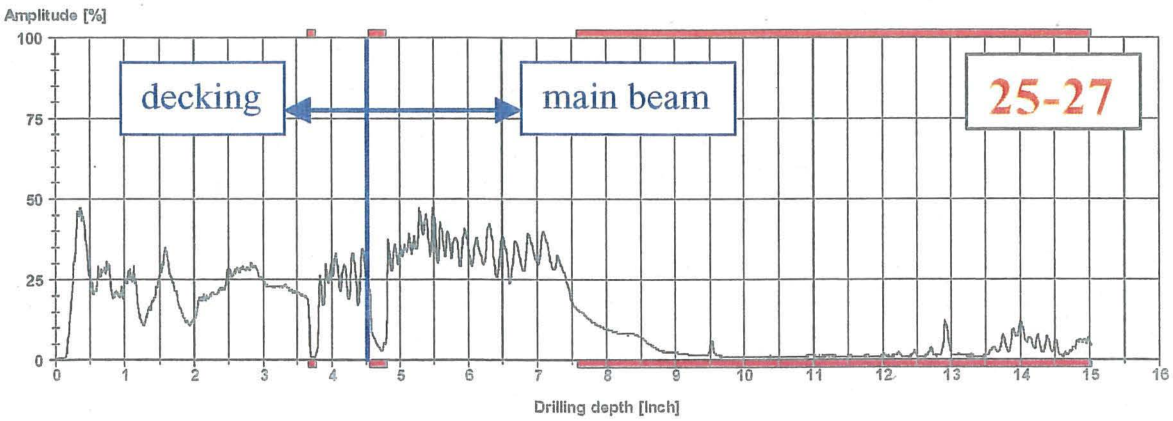
Appendix C6

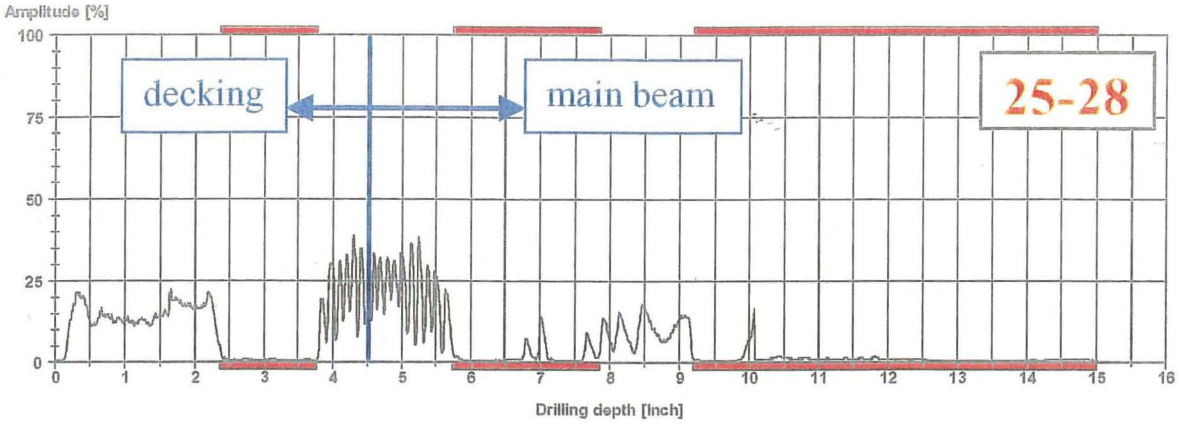
Resistance Micro-Drilling Plots

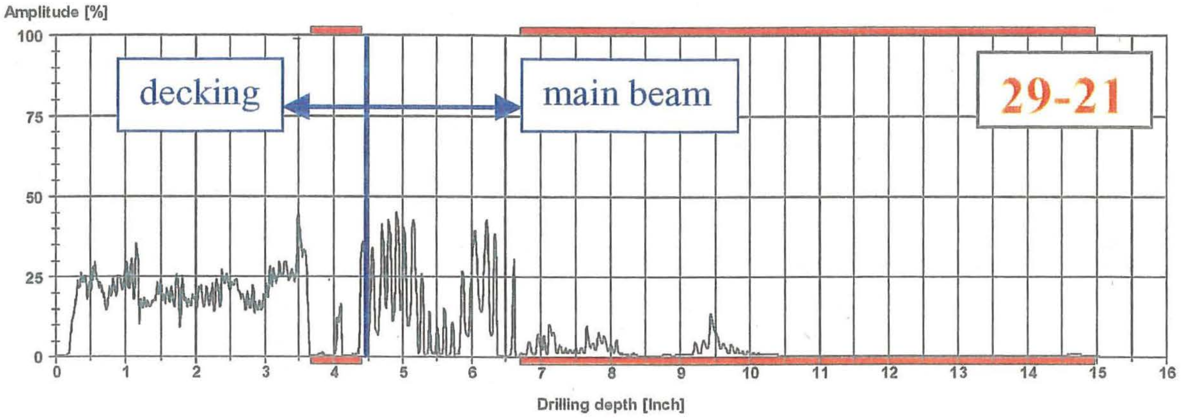
Main Deck Beams

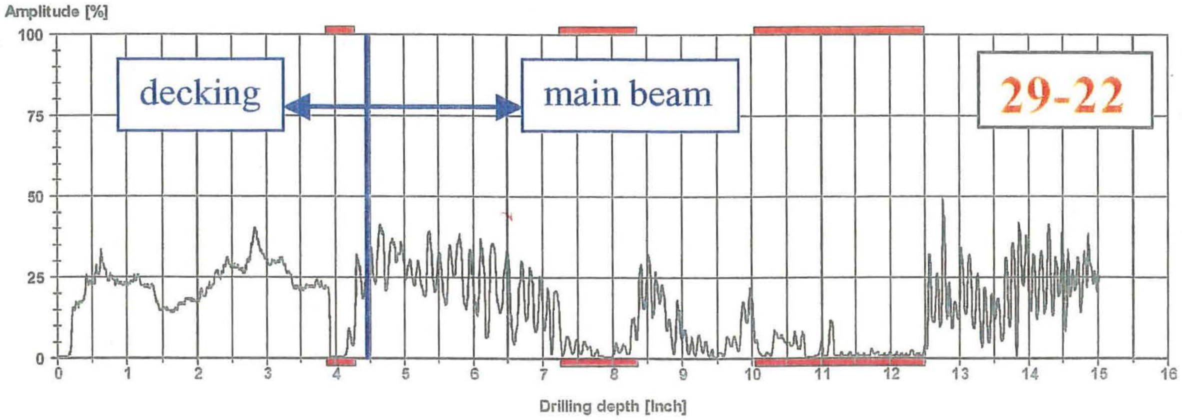

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
decking
main beam
25-21

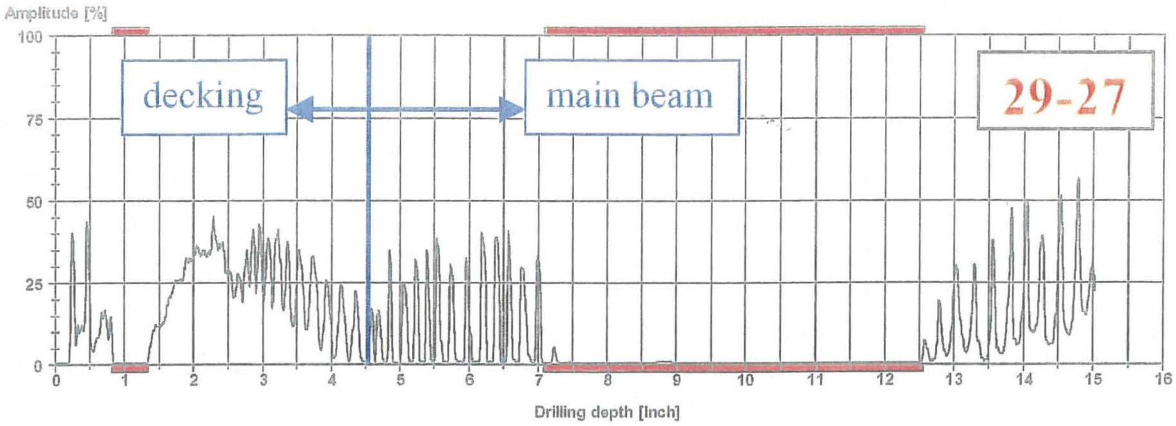

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
decking
main beam
25-22

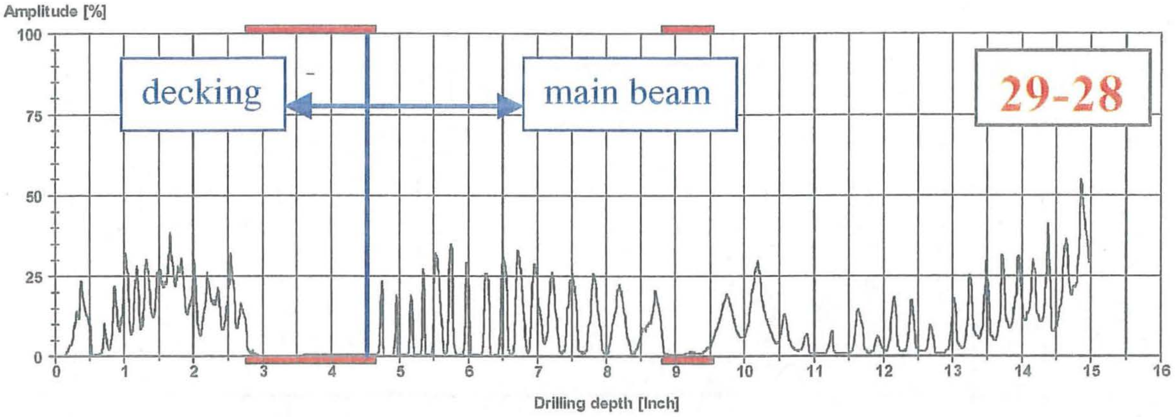

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]
decking
main beam
25-27

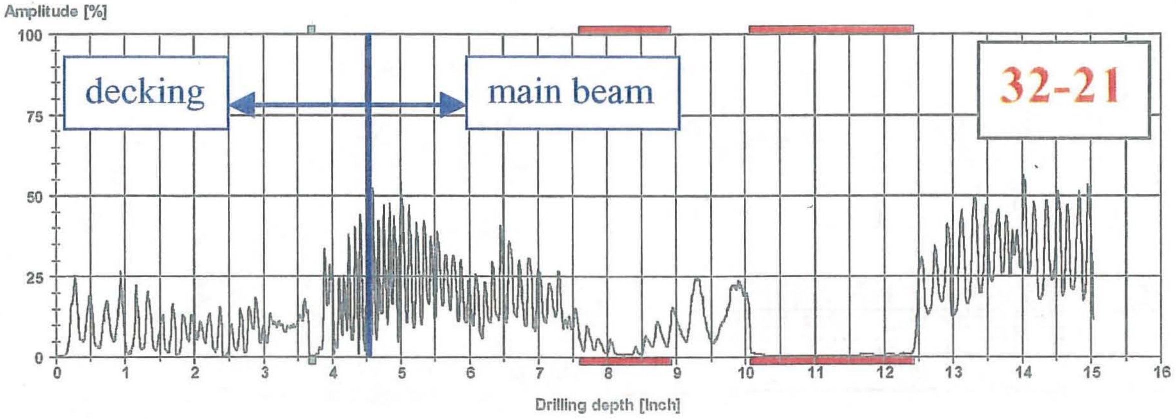

Amplitude [%]
100
75
50
25
0
decking
main beam
25-28
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]

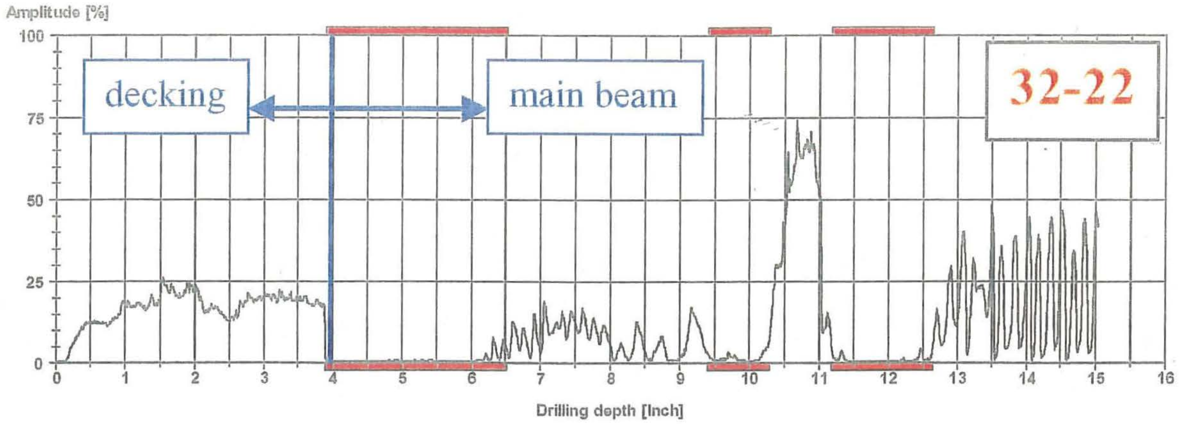

Amplitude [%]
100
75
50
25
0
decking
main beam
29-21
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]

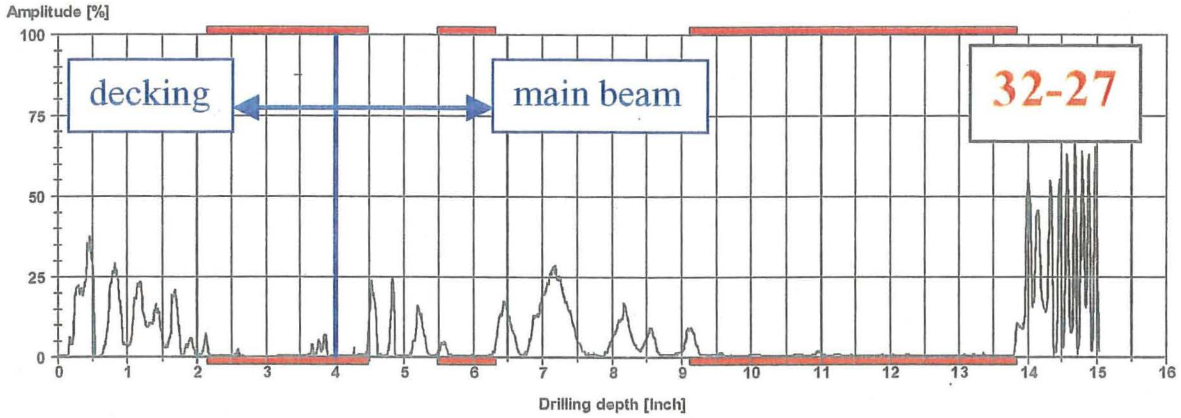

Amplitude [%]
100
75
50
25
0
decking
main beam
29-22
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]

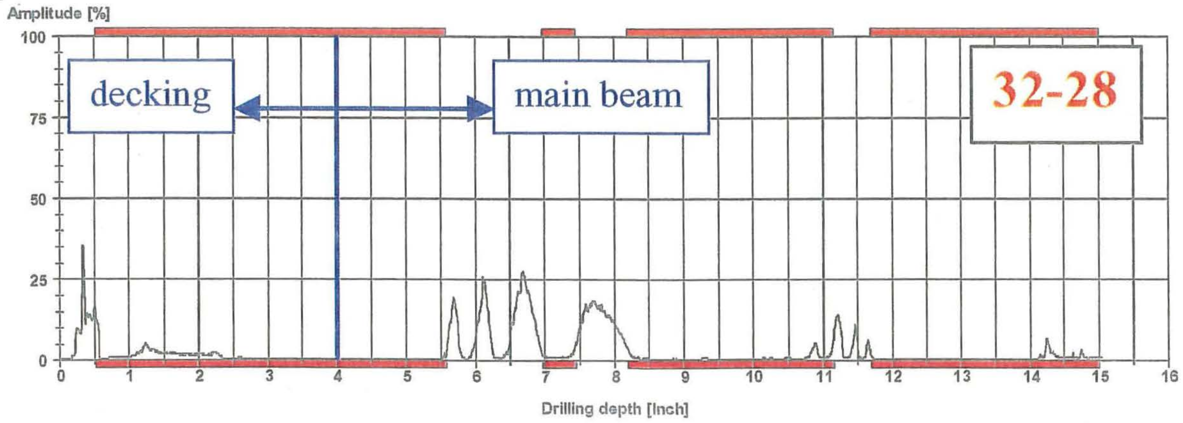

Amplitude [%]
100
75
50
25
0
decking
main beam
29-27
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

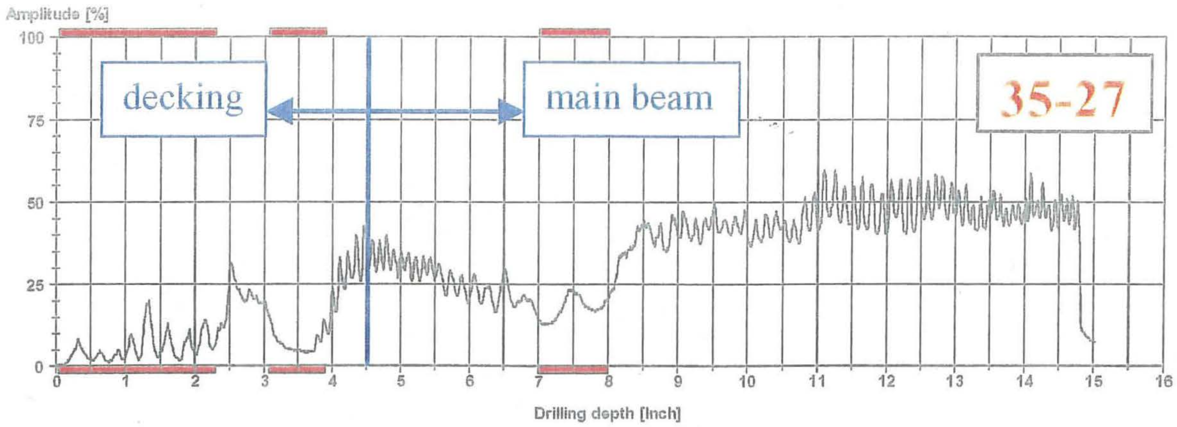

Amplitude [%]
100
75
50
25
0
decking
main beam
29-28
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

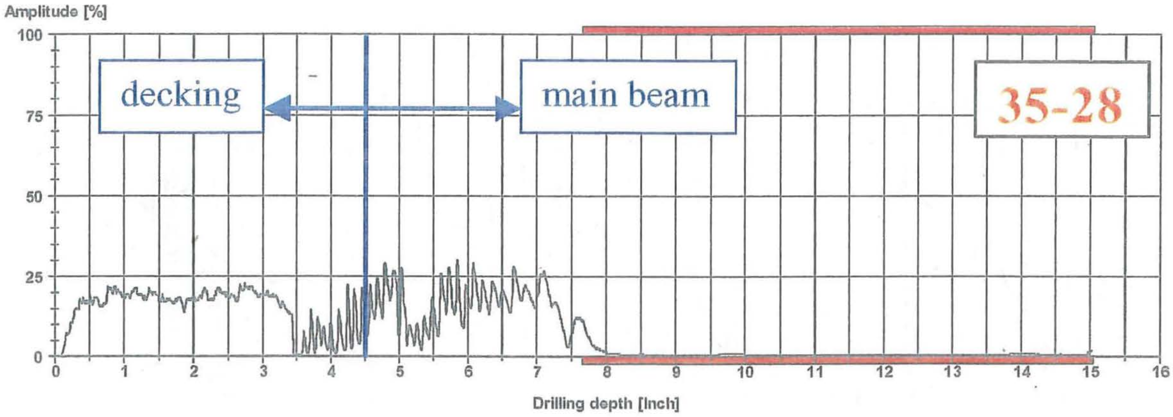

Amplitude [%]
100
75
50
25
0
decking
main beam
32-21
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

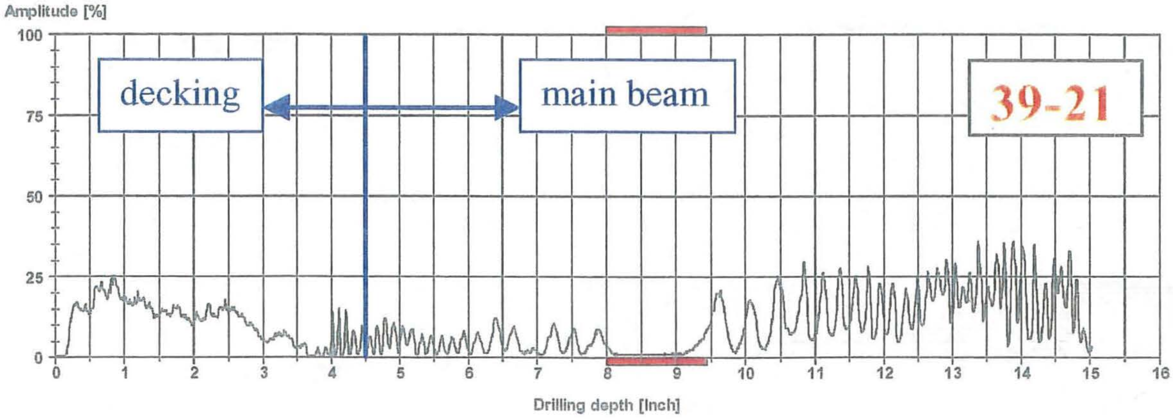

Amplitude [%]
100
75
50
25
0
decking
main beam
32-22
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

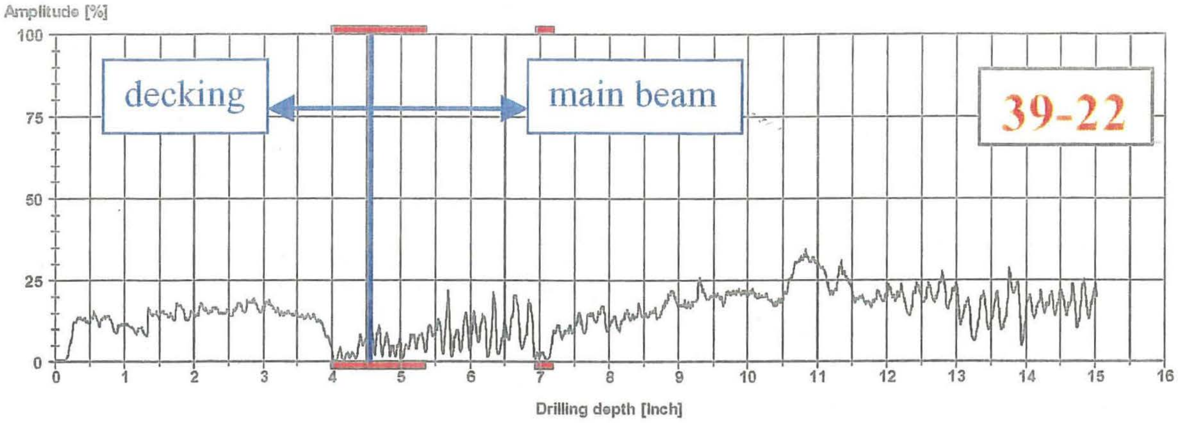

Amplitude [%]
100
75
50
25
0
decking
main beam
32-27
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

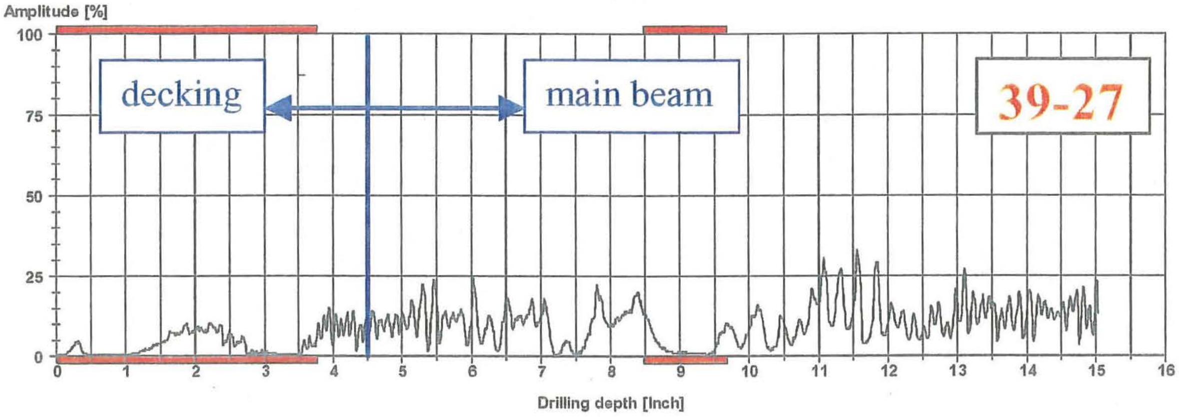

Amplitude [%]
100
75
50
25
0
decking
main beam
32-28
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

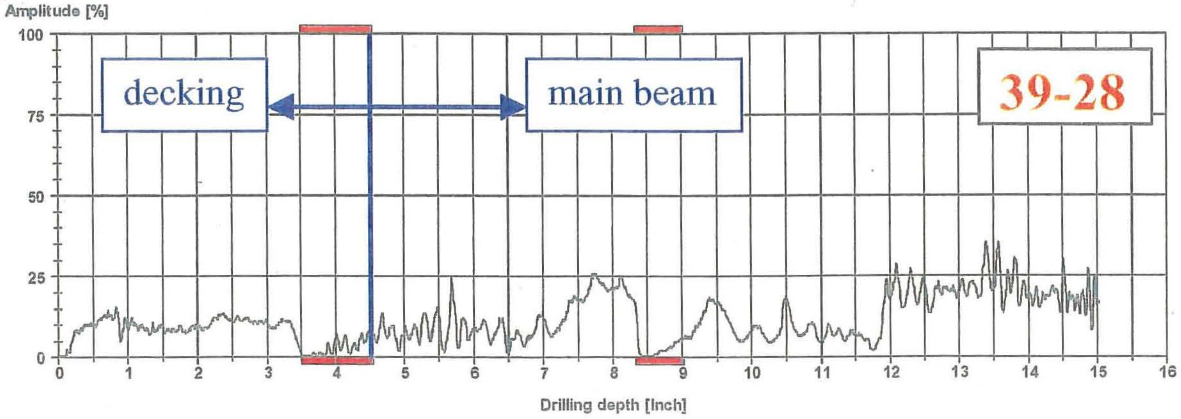

Amplitude [%]
100
75
50
25
0
decking
main beam
35-27
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

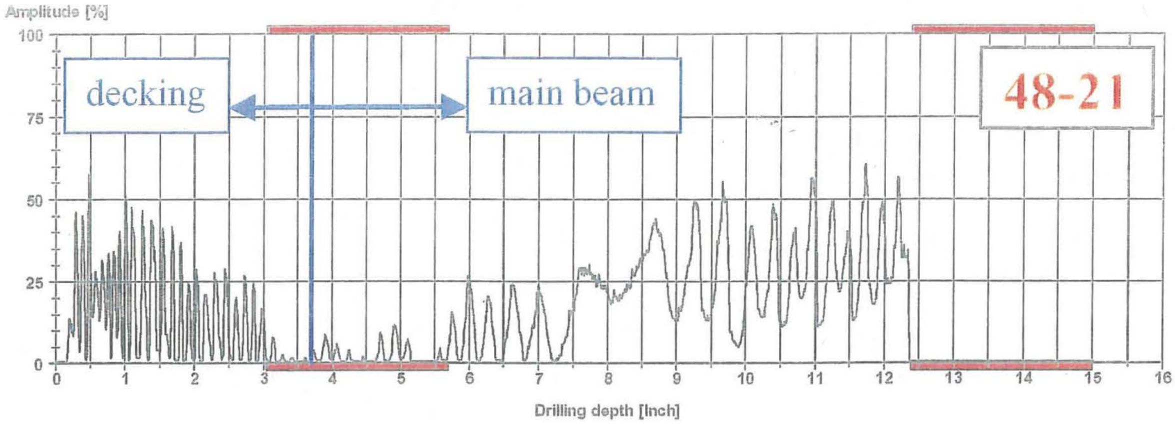

Amplitude [%]
100
75
50
25
0
decking
main beam
35-28
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

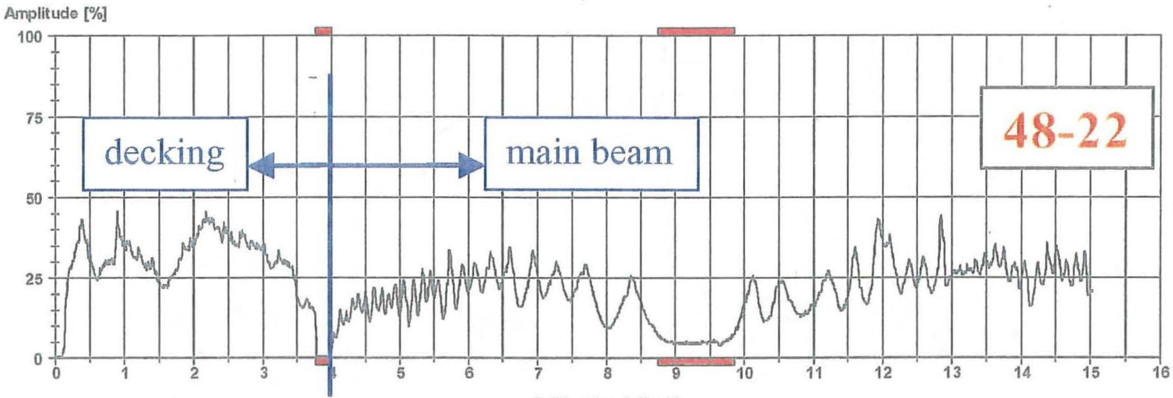

Amplitude [%]
100
75
50
25
0
decking
main beam
39-21
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

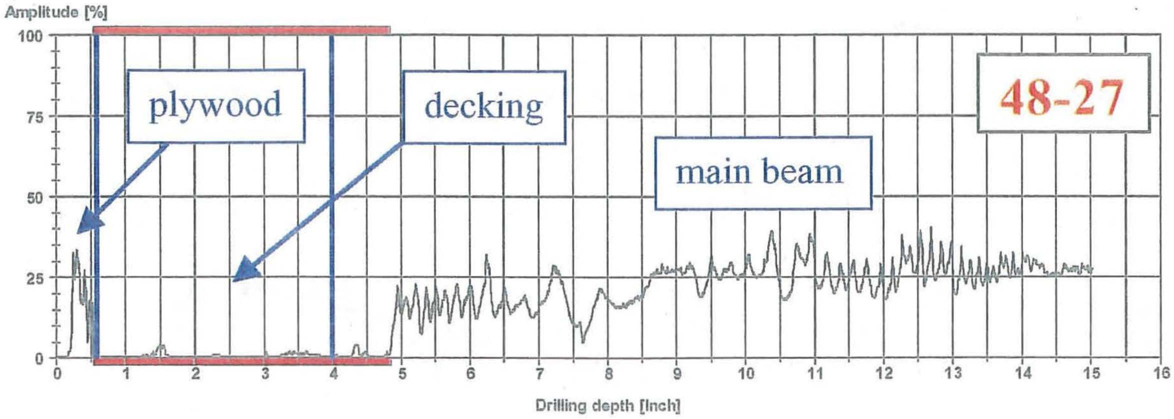

Amplitude [%]
100
75
50
25
0
decking
main beam
39-22
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

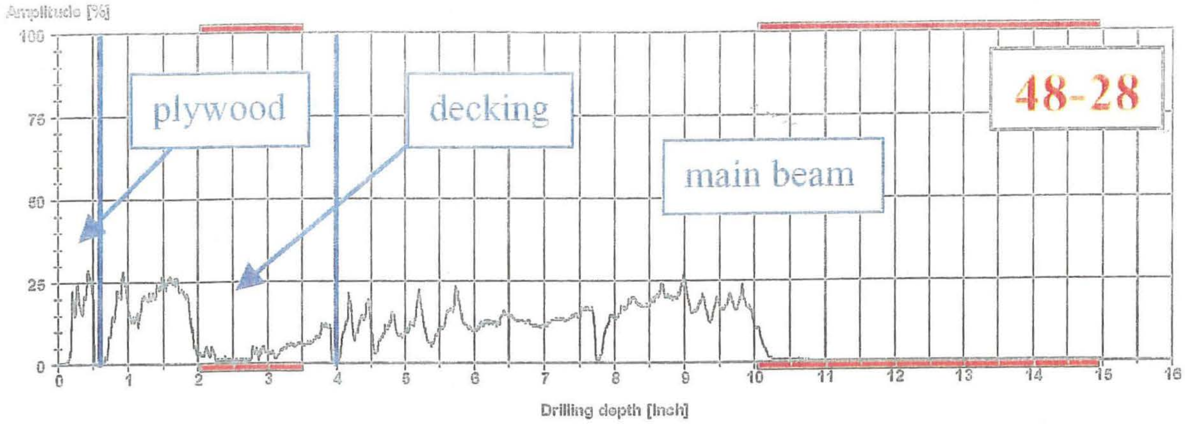

Amplitude [%]
100
75
50
25
0
decking
main beam
39-27
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]


Amplitude [%]
100
75
50
25
0
decking
main beam
39-28
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]


Amplitude [%]
100
75
50
25
0
decking
main beam
48-21
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]


Amplitude [%]
100
75
50
25
0
decking
main beam
48-22
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

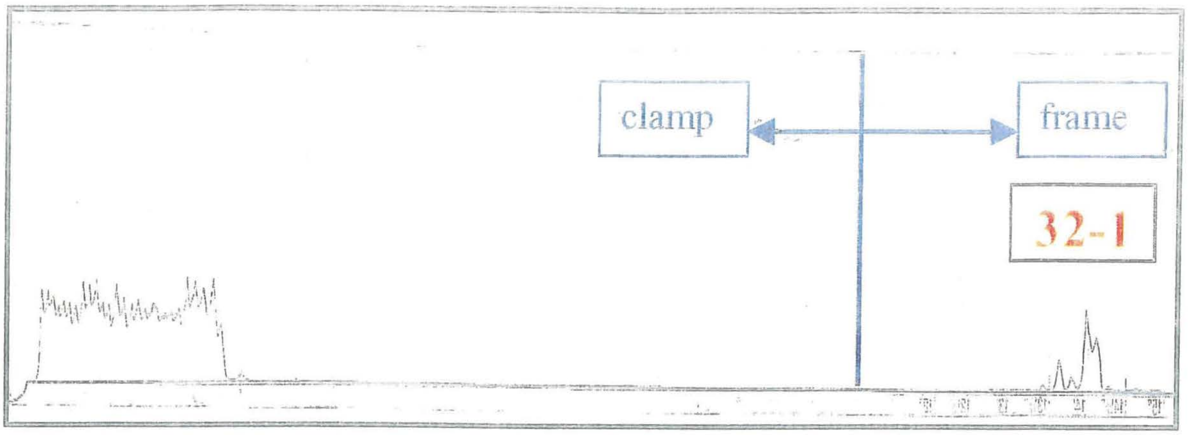

Amplitude [%]
100
75
50
25
0
plywood
decking
main beam
48-27
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [Inch]

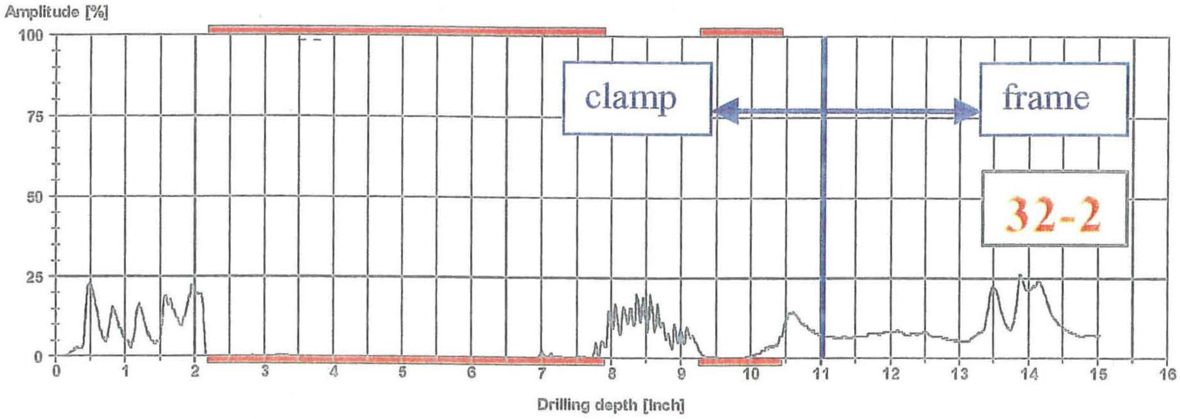

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
plywood
decking
main beam
48-28

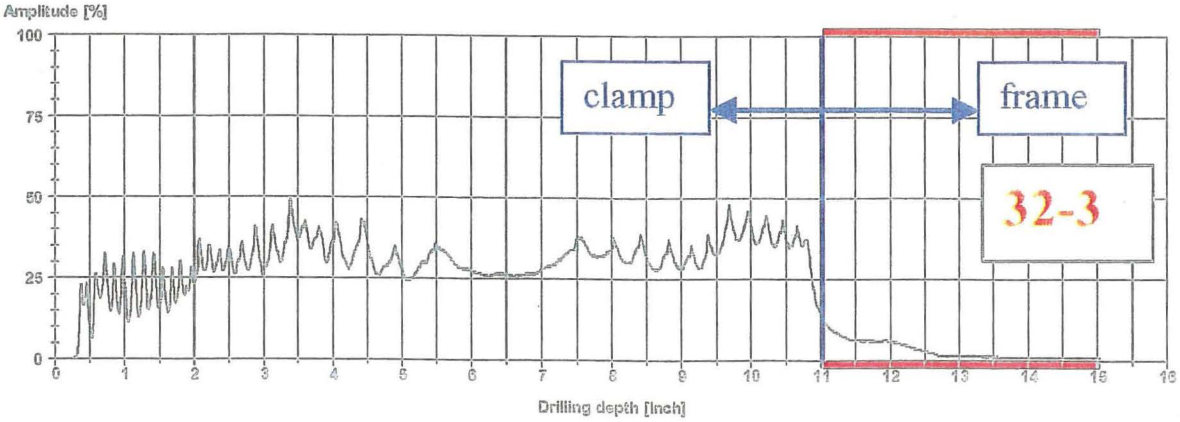
Appendix C7

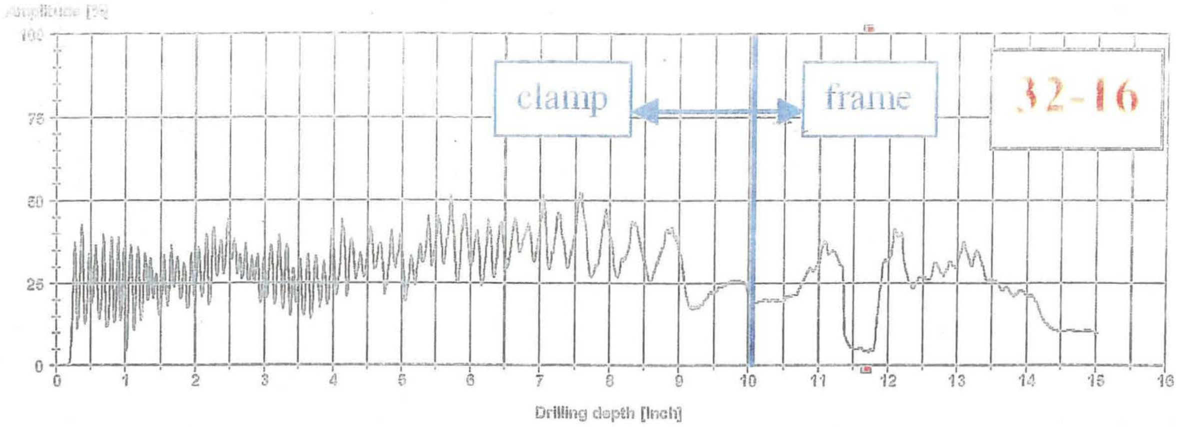
Resistance Micro-Drilling Plots

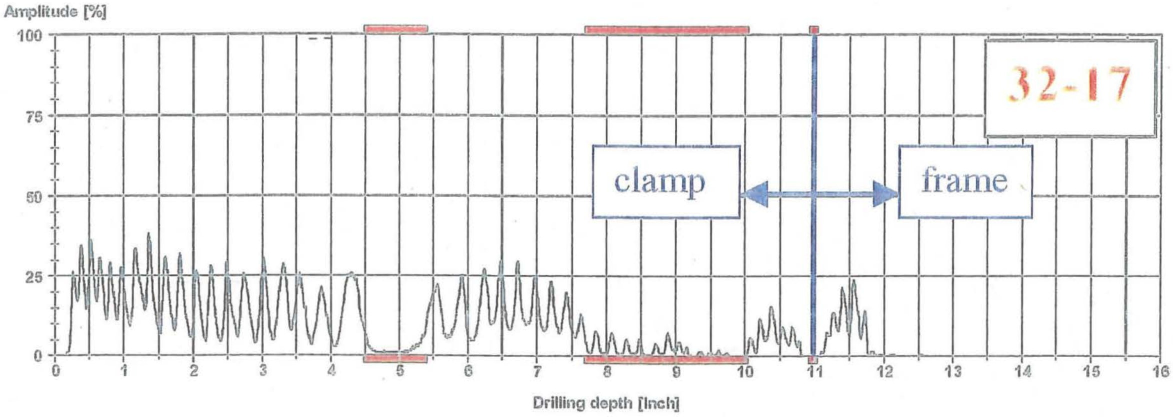
Beam Clamps & Bulwarks

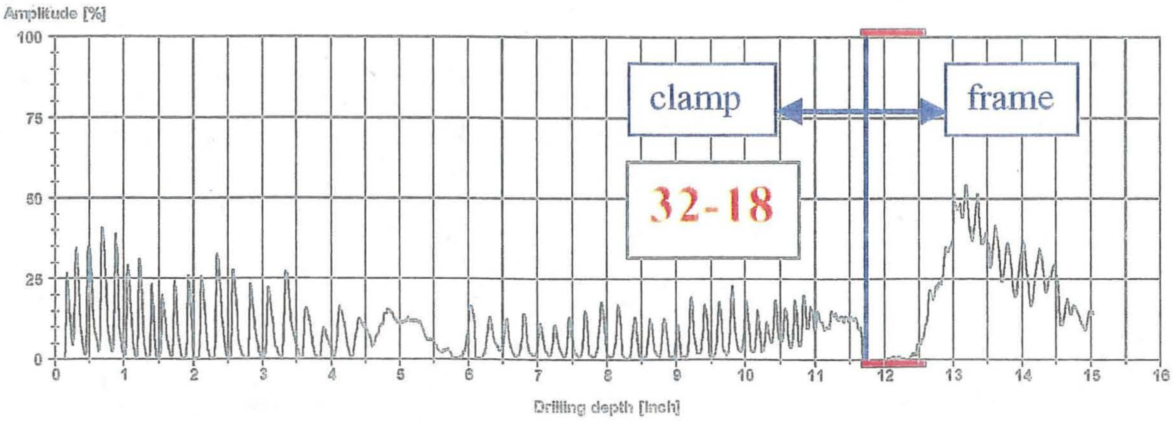

clamp
frame
32-1

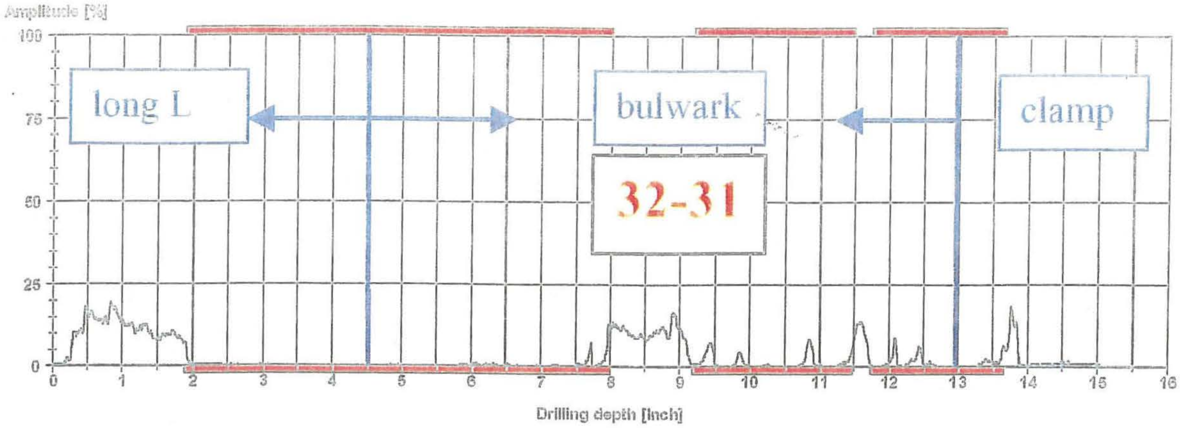

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
clamp
frame
32-2

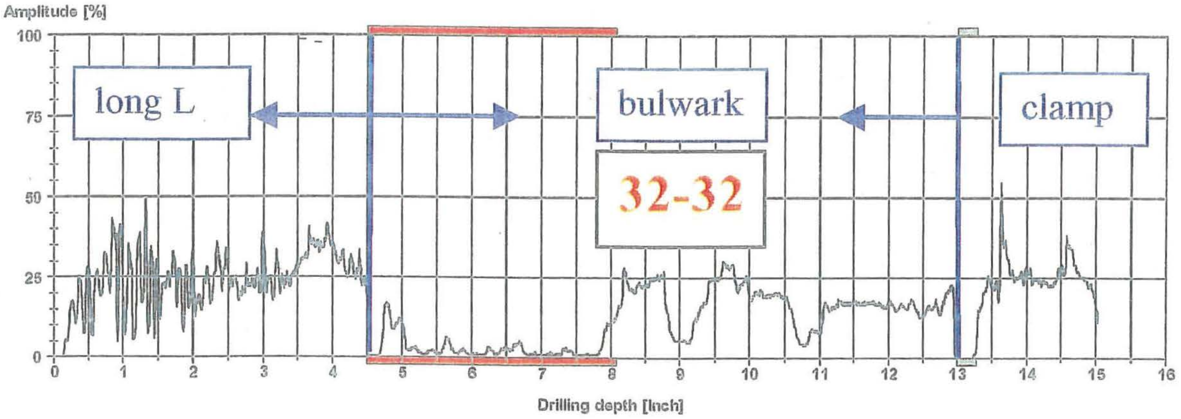

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
clamp
frame
32-3

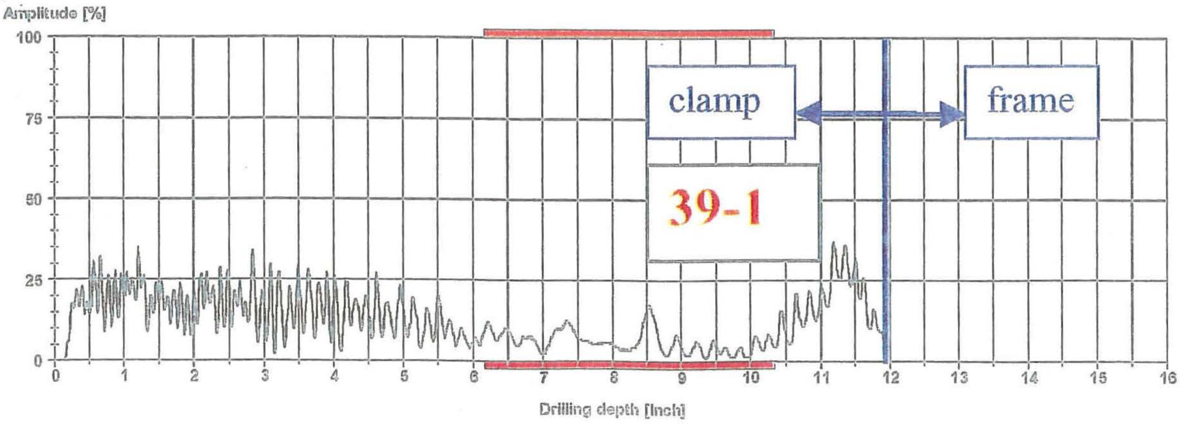

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
clamp
frame
32-16

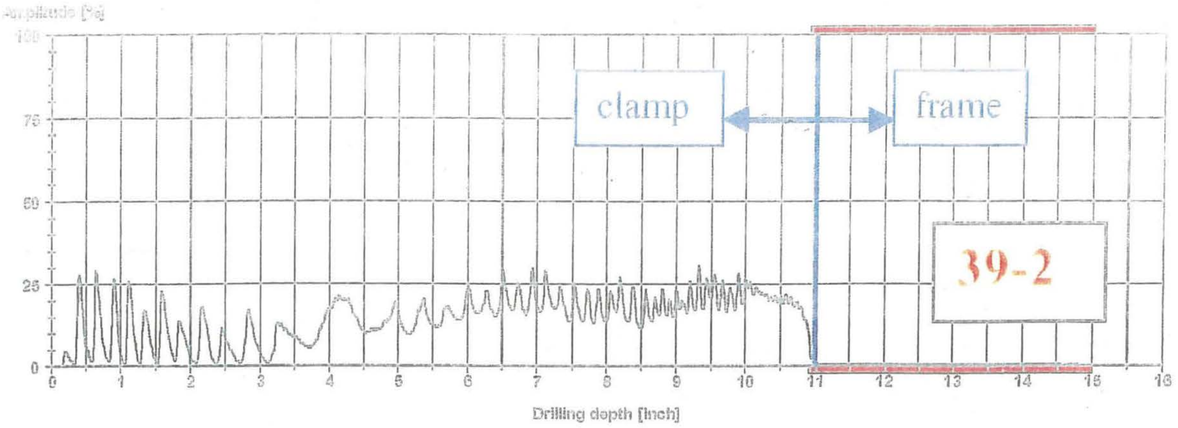

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
clamp
frame
32-17

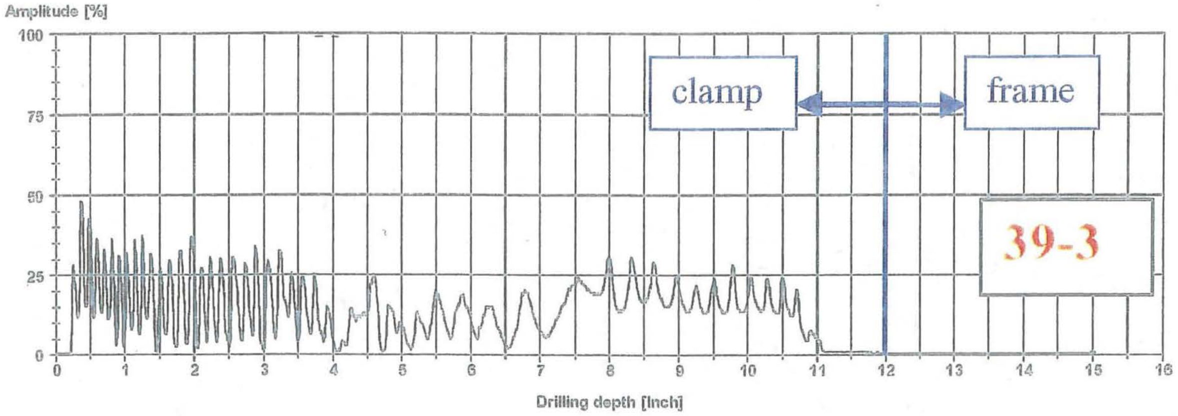

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
clamp
frame
32-18

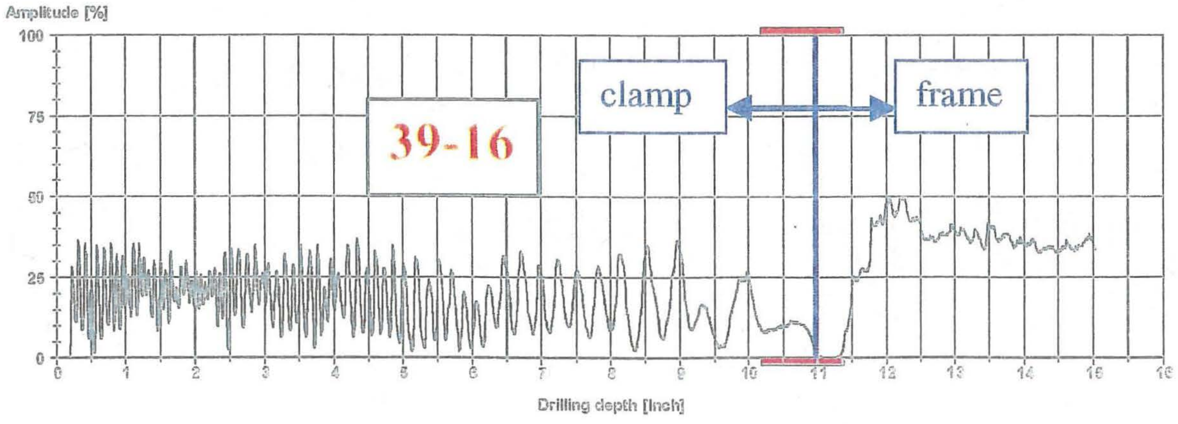

Amplitude [%]
100
75
50
25
0
long L
bulwark
clamp
32-31
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]

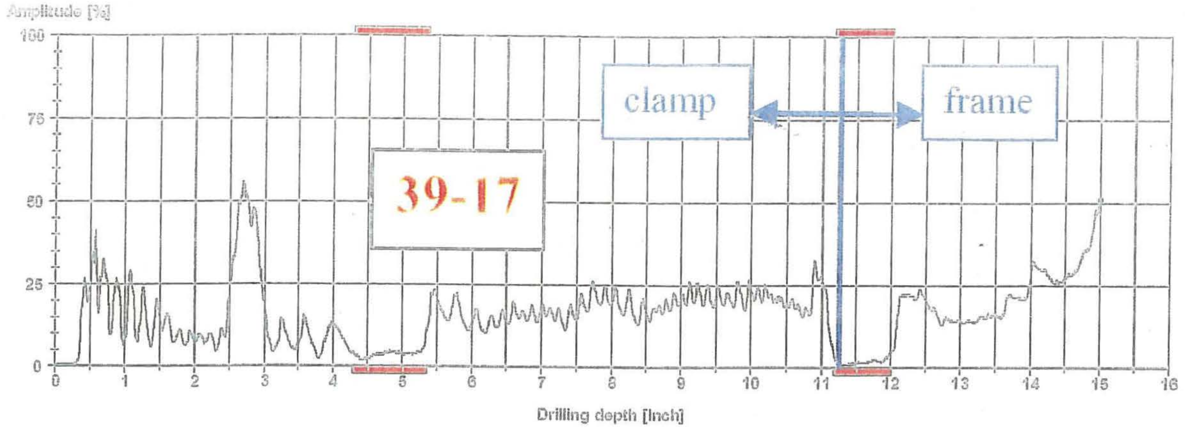

Amplitude [%]
100
75
50
25
0
long L
bulwark
clamp
32-32
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]

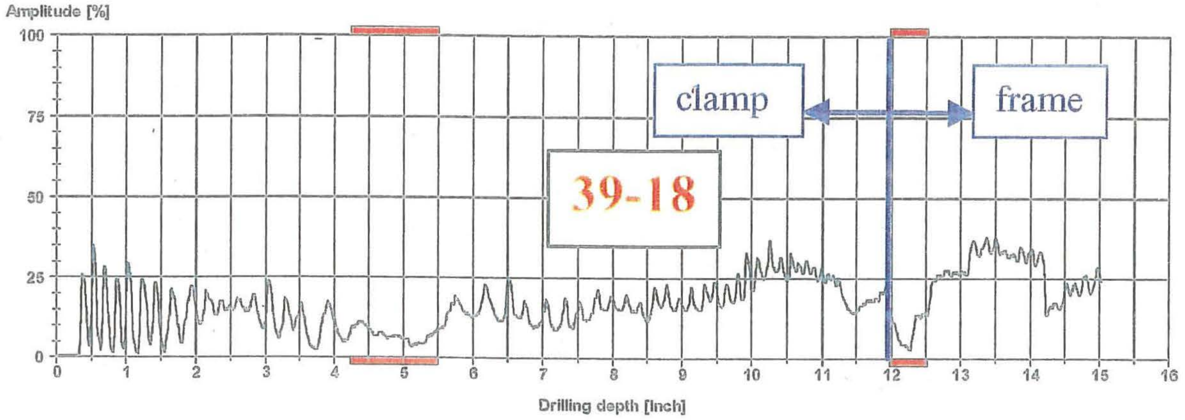

Amplitude [%]
100
75
50
25
0
clamp
frame
39-1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]

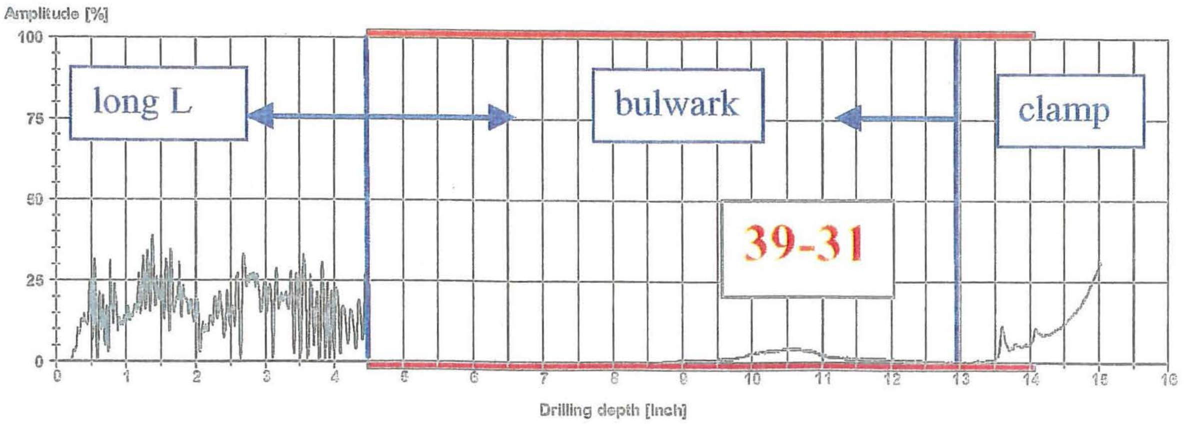

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]
clamp
frame
39-2

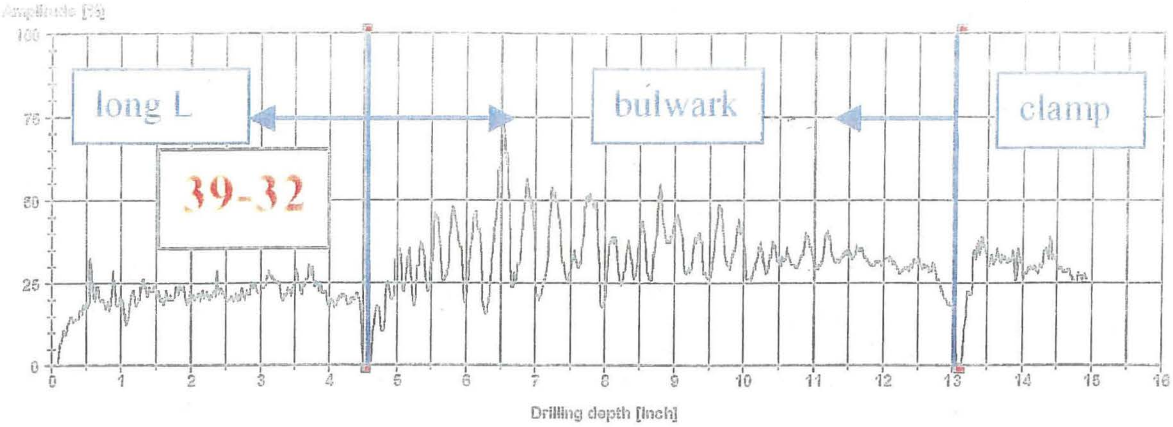

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]
clamp
frame
39-3

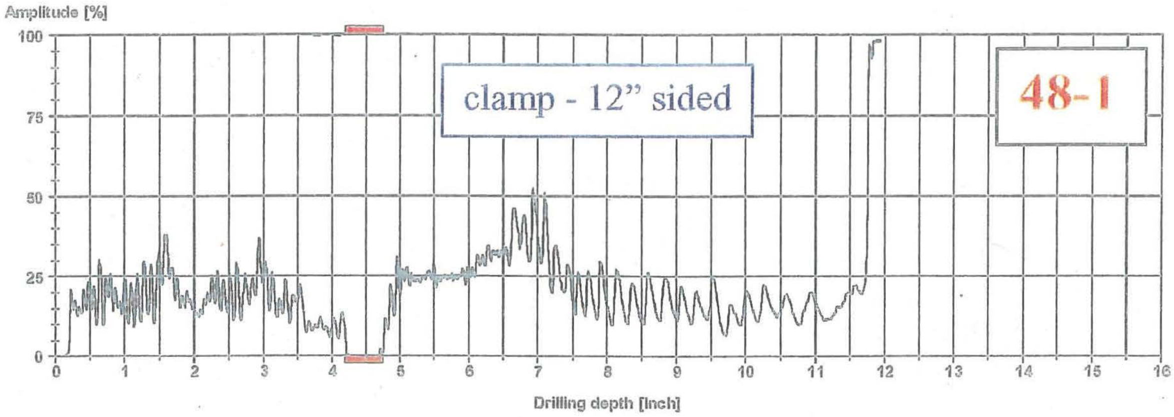

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]
clamp
frame
39-16

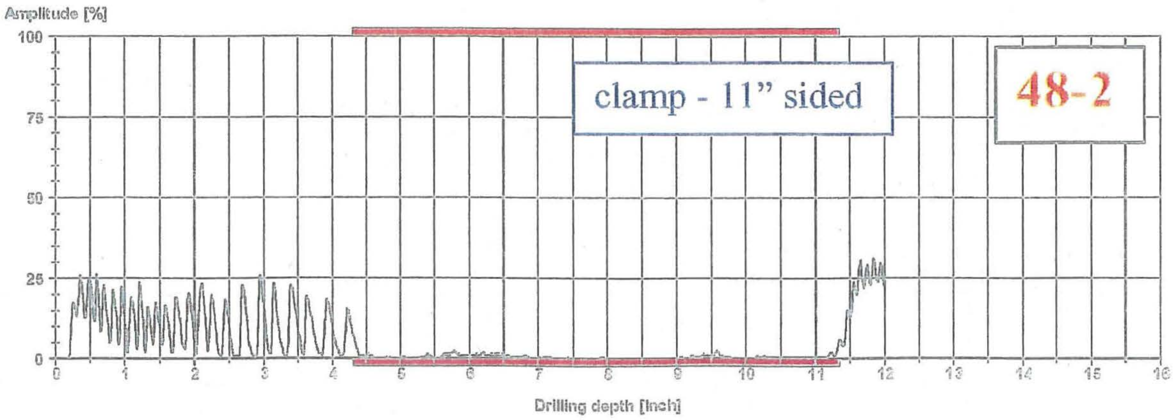

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
clamp
frame
39-17

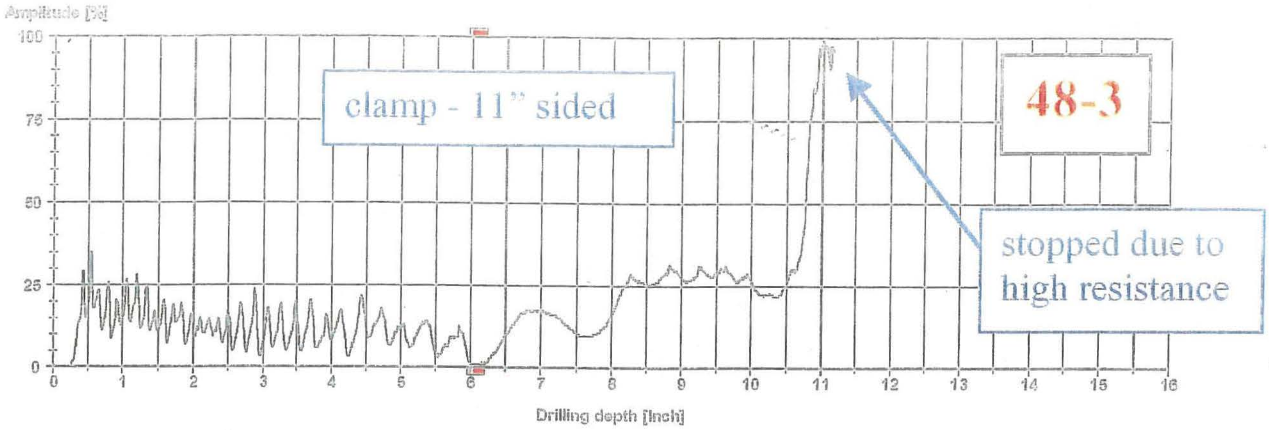

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
clamp
frame
39-18

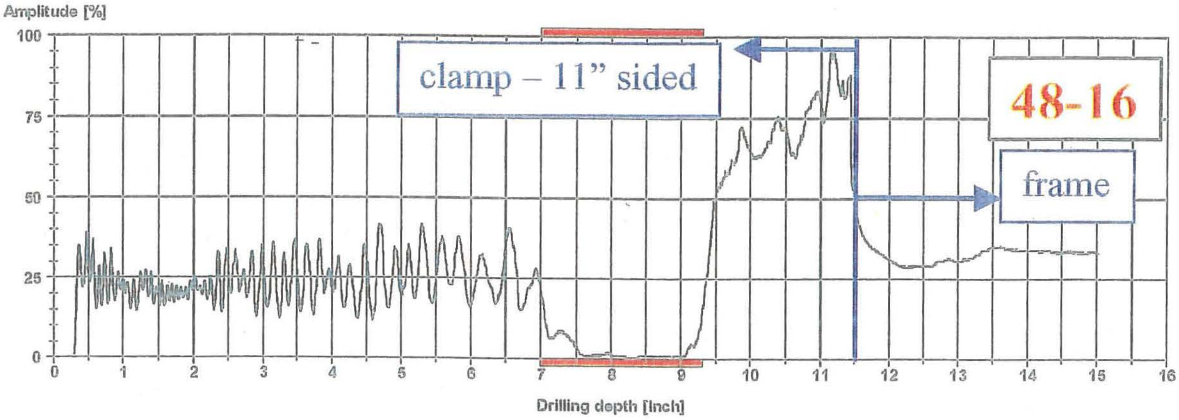

Amplitude [%]
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Drilling depth [inch]
long L
bulwark
clamp
39-31

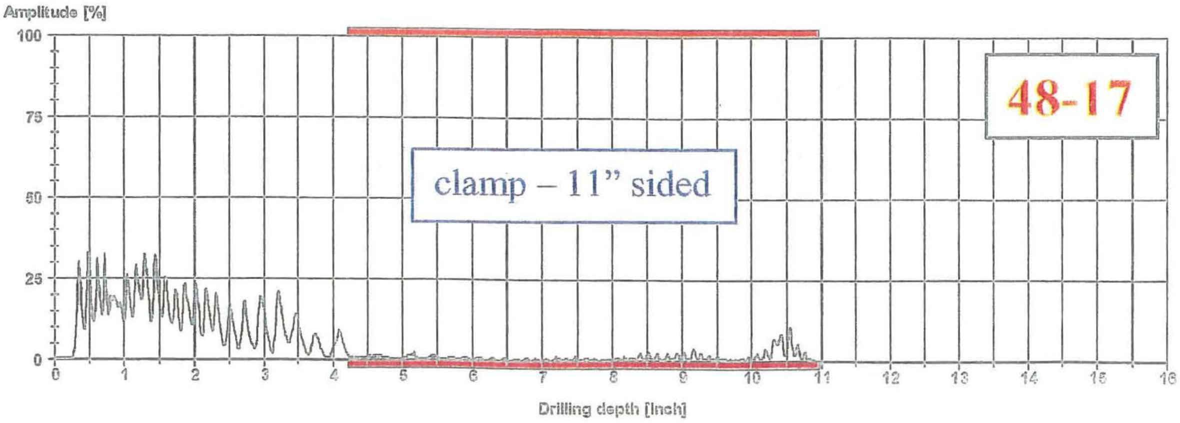

Amplitude [%]
100
75
50
25
0
long L
39-32
bulwark
clamp
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]

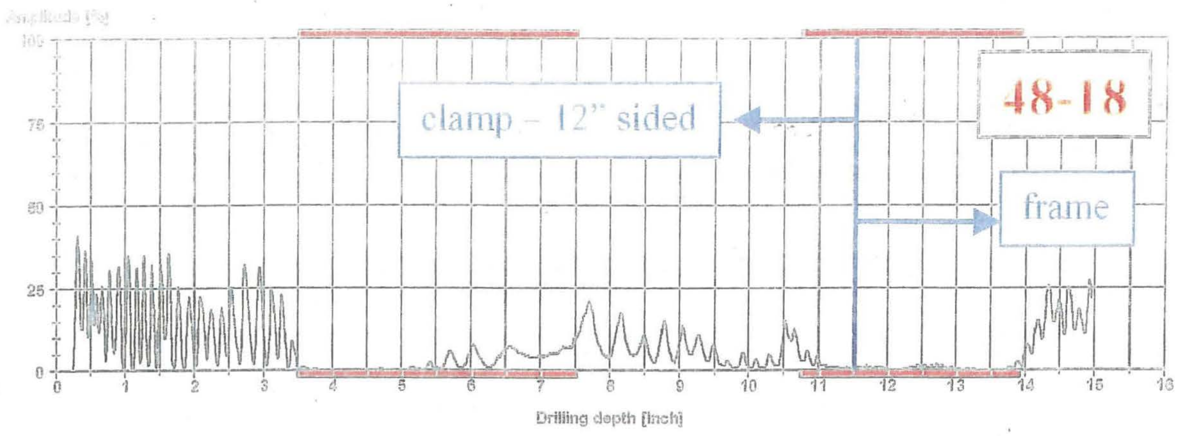

Amplitude [%]
100
75
50
25
0
clamp - 12" sided
48-1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]

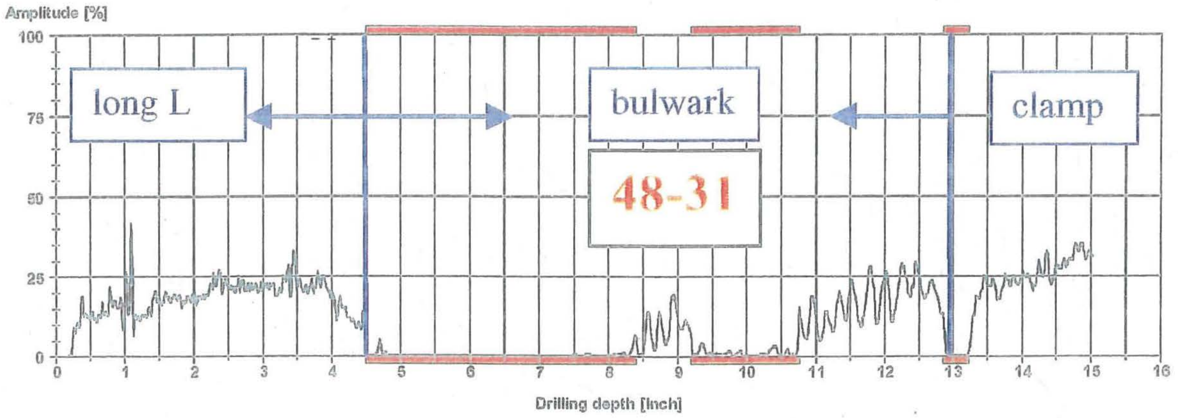

Amplitude [%]
100
75
50
25
0
clamp - 11" sided
48-2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]

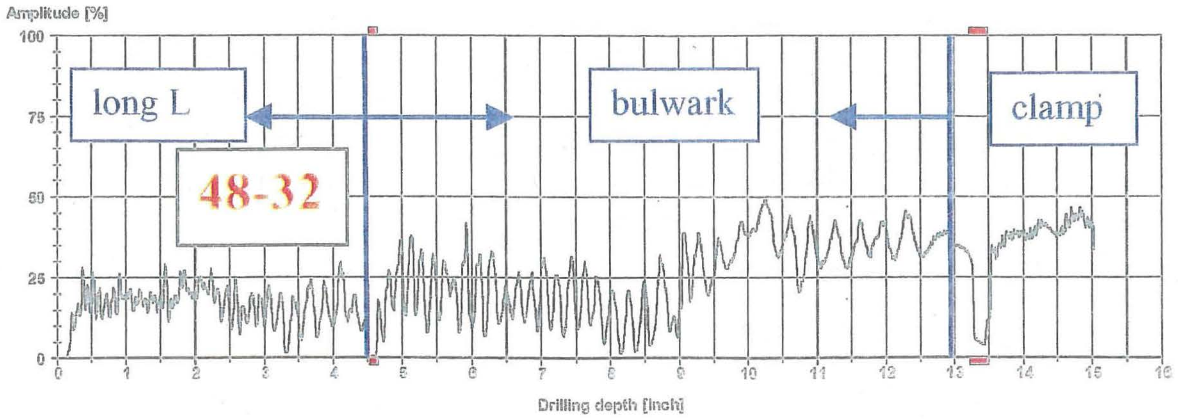

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]
clamp - 11" sided
48-3
stopped due to high resistance


Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]
clamp – 11" sided
48-16
frame


Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]
48-17
clamp – 11" sided


Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]
clamp – 12" sided
48-18
frame

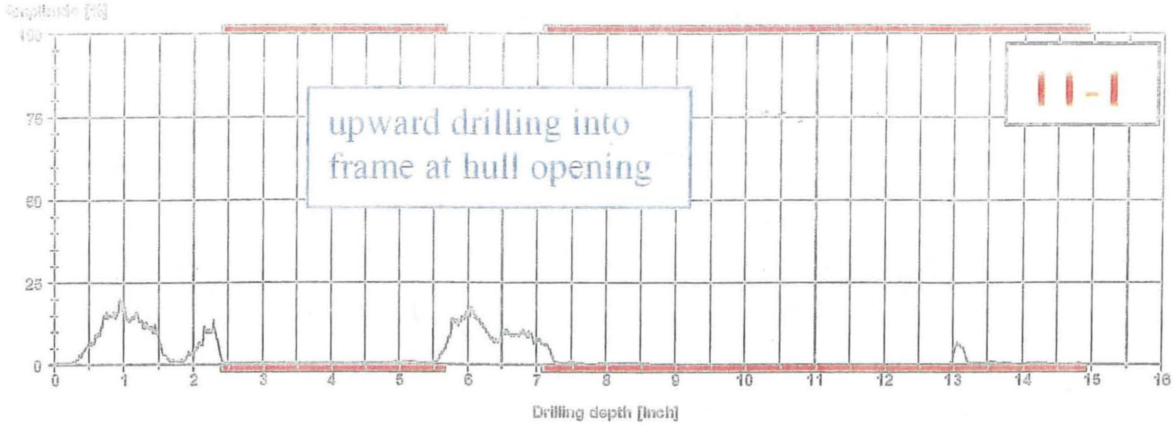

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]
long L
bulwark
48-31
clamp

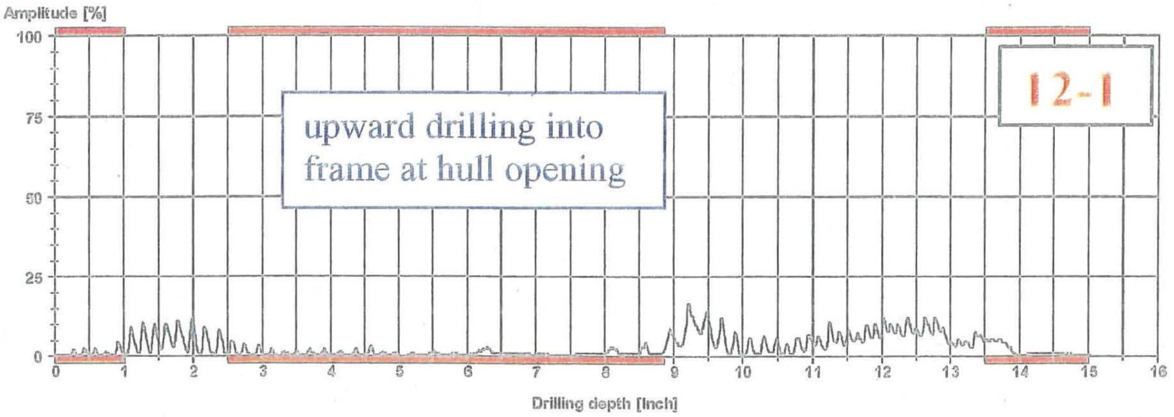

Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [inch]
long L
48-32
bulwark
clamp

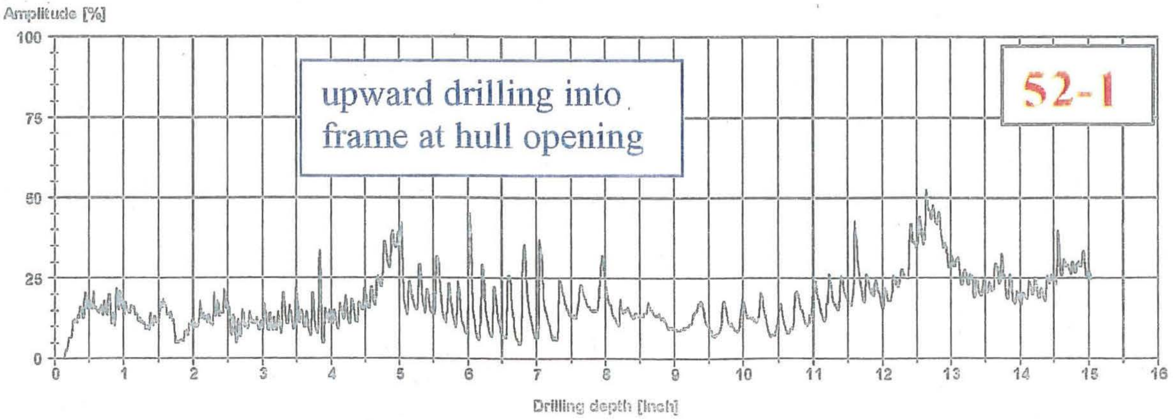
Appendix C8

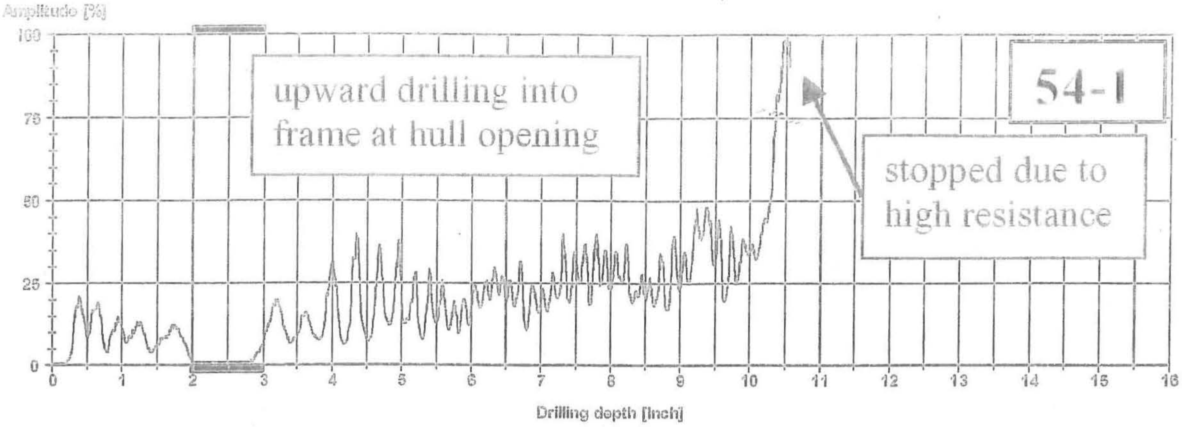
Resistance Micro-Drilling Plots

Frames at Outside Hull Openings


Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
upward drilling into frame at hull opening
11-1


Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
upward drilling into frame at hull opening
12-1


Amplitude [%]
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Drilling depth [Inch]
upward drilling into frame at hull opening
52-1



upward drilling into frame at hull opening

stopped due to high resistance

Appendix D

Stress Wave Timing Nondestructive Evaluation Tools for Inspecting Historic Structures

– A Guide for Use and Interpretation.

United States
Department of
Agriculture

Forest Service

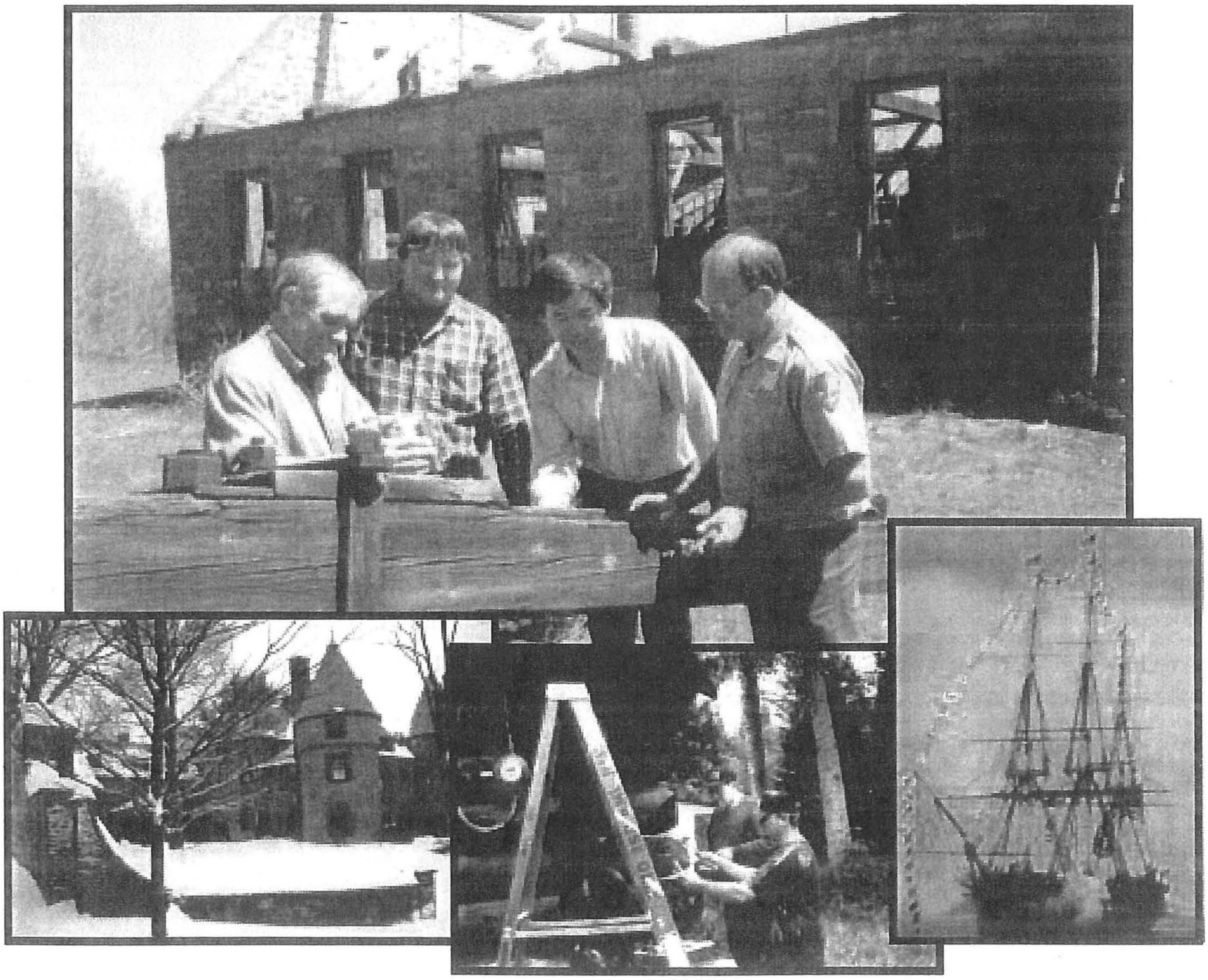
Forest
Products
Laboratory

General
Technical
Report
FPL–GTR–119

NCPTT

Stress Wave Timing Nondestructive Evaluation Tools for Inspecting Historic Structures

A Guide for Use and Interpretation



Abstract

This guide was prepared to assist inspectors in the use of stress wave timing instruments and various methods of locating and defining areas of decay in timber members in historic structures. The first two sections provide (a) background information regarding conventional methods to locate and measure decay in historic structures and (b) the principles of stress wave nondestructive testing and measurement techniques. The last section is a detailed description of how to apply the use of stress wave nondestructive testing methods in the field. A sample field data acquisition form and additional reference material are included in the Appendix. This guide includes all the information needed to begin to utilize and interpret results from stress wave timing nondestructive evaluation methods.

Keywords: Nondestructive evaluation, property evaluation, historic structure

April 2000

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Preface

The information in this publication is intended for those who inspect historic structures. This report is a minor revision of a 1999 publication entitled *Inspection of Timber Bridges Using Stress Wave Timing Nondestructive Evaluation Tools—A Guide for Use and Interpretation* by Robert J. Ross, Roy F. Pellerin, Norbert Volny, William W. Salsig, and Robert H. Falk, USDA Forest Service, Forest Products Laboratory (Ross and others 1999). The basic technology used to inspect both timber bridges and historic structures is essentially the same.

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Stress Wave Timing Nondestructive Evaluation Tools for Inspecting Historic Structures

A Guide for Use and Interpretation

Introduction

Background

Until recently, the preservation and restoration of historically and architecturally significant buildings has represented an effort to preserve America's heritage. Now, more tangible factors, couched in economics, may underlie the growing interest in preservation and restoration. Investing in the preservation of older neighborhoods reduces taxpayer-funded costs for extending municipal infrastructure to outlying urban sprawl. In addition, restoration and preservation of structures in older neighborhoods is environmentally sound in terms of recycling building materials and resources.

Wood was extensively used for both interior and exterior applications in the construction of historic buildings, regardless of use (residential, agriculture, commercial, government, religious). Therefore, much restoration and preservation involves solving technical problems associated with the economical use, reuse, and care of wood.

For the most part, information on wood science and engineering is generic to construction practices; that is, it is applicable to both new and restorative construction. This information provides the knowledge base for preservation and restoration. However, detailed science-based information is needed to address problems specific to historic structures, such as problems associated with the deteriorating influence of age and the customarily inadequate and inconsistent maintenance of historic structures. In addition, the restoration of historic structures presents a unique problem. Historic preservation organizations and owners of historic buildings place constraints on allowable construction practices. These constraints involve rigid requirements concerning salvage, reuse, and maintenance of the original materials, such as replacement of deteriorated materials with material of the same species and type as that of the original structure or restoration using state-of-the-art materials and techniques to accomplish the same visual effect as that of the original construction. The focus ranges from an effort to achieve "museum quality" restoration to an emphasis on practical and economic restoration. In some cases, the kind of restoration may be driven by economic incentives.

Determining an appropriate load rating for a historic structure and making rational decisions about rehabilitation, repair, or replacement necessitate an accurate assessment of the building's condition. Knowledge of the condition of the structure can lead to savings in repair and replacement costs by minimizing labor and materials and extending service life.

The quality, hence value, of a timber inspection depends on the level of experience of the inspector and the inspection tools available. For example, inspecting timber members for decay using hammer sounding is limited in its effectiveness to very experienced inspectors, who must by ear interpret the sound of a hammer blow to the timber member. In addition, hammer sounding is not effective on members greater than 89 mm (3.5 in.) thick. Although methods such as coring and drilling are often used to verify potential trouble spots found with the sounding method, coring and drilling can be rather destructive to the member and potentially open the interior of the member to decay attack.

Although not widely used, nondestructive testing using stress wave timing is an available method that offers the ability to determine the presence of internal decay in timbers. Advanced training to use this method is not required, although the method does require experience in wood inspection. The nondestructive testing method can serve as an additional tool to definitively determine the condition of a timber.

Purpose

The purpose of this document is to provide guidelines on the application and use of the stress wave timing inspection method to locate and define areas of decay in timber members. A review of the basics of stress wave theory is provided, as well as a description of available equipment, practical procedures for field testing, workable forms for gathering evaluation data, and guidelines for interpretation of data. This information was derived from research performed to quantify the ability of stress wave timers to detect decay in wood, from laboratory and field studies of deteriorated structural members, and most importantly from the experience of inspectors familiar with the use of these devices. Overviews of the properties of wood and important aspects of wood deterioration are also given to provide those unfamiliar with wood the basic information necessary to detect decay.

This guide is intended for wood structure inspectors. The authors have made a concerted effort to provide clear and concise explanations of the operation and use of stress wave equipment for the nondestructive testing of historic structures. For those interested in detailed information on wood properties, stress wave theory, or wood structure maintenance, additional reference material is listed in the Appendix.

Conventional Methods

In this section, conventional methods of inspection are briefly reviewed. Methods to detect deterioration in structural members are divided into two categories: those for exterior deterioration and those for interior deterioration. In both cases, specific methods or tools appropriate to detect and locate decay and their usefulness vary depending on the type and size of the member. Although a variety of inspection methods may be used, in practice the inspector uses only a few tools. The methods or tools are often dictated by budget, previous experience, and the types of problems encountered.

Exterior Deterioration

Exterior deterioration is the easiest type of decay to detect because it is often readily accessible to the inspector. The ease of detection depends on the severity of damage and the method of inspection. Commonly used methods include visual inspection and probing. When areas of exterior deterioration are located by these methods, additional investigation by other methods is needed to confirm and define the extent of damage.

Visual Inspection

The simplest method for locating deterioration is visual inspection. The inspector observes the structure for signs of actual or potential deterioration, noting areas for further investigation. Visual inspection requires strong light and is useful for detecting intermediate or advanced surface decay. Visual inspection cannot detect decay in the early stages, when remedial treatment is most effective, and should never be the only method used. Observations that are possible with visual inspection include the following:

- Fruiting bodies provide positive indication of fungal attack, but do not indicate the amount or extent of decay. Some fungi produce fruiting bodies after small amounts of decay have occurred; others develop only after decay is extensive. Although fruiting bodies are not common, when present, they almost certainly indicate a serious decay problem.
- Sunken faces or localized surface depressions can indicate underlying decay. Decay voids or pockets may develop close to the surface of the member, leaving a thin, depressed layer of intact or partially intact wood at the surface. Crushed wood can also be an indicator of decay.
- Staining or discoloration indicates that the wood has been subjected to water and potentially a high moisture content suitable for decay. Rust stains from connection hardware are also a good indication of wetting.
- Insect activity is visually characterized by holes, frass, powder posting, or other signs. The presence of insect activity may also indicate the presence of decay.
- Plant or moss growth in splits and cracks or soil accumulation on the structure indicates that adjacent wood has been at a relatively high moisture content for a sustained period and may sustain growth of decay fungi.

Probing

Probing with a moderately pointed tool, such as an awl or knife, locates decay near the wood surface as indicated by excessive softness or a lack of resistance to probe penetration and the breakage pattern of the splinters. A brash break indicates decayed wood, whereas a splintered break reveals sound wood. Although probing is a simple inspection method, experience is required to interpret results. Care must be taken to differentiate between decay and water-softened wood, which may be sound but somewhat softer than dry wood. It is also sometimes difficult to assess damage in soft-textured woods such as western redcedar.

Interior Deterioration

Unlike exterior deterioration, interior deterioration is difficult to locate because no visible signs of decay may be present. Many methods and tools have been developed to evaluate internal damage, ranging in complexity from sounding the surface with a hammer to sophisticated radiographic evaluation. Tools, such as moisture meters, are also used to help the inspector identify areas where conditions are suitable for development of internal decay.

Sounding

Sounding the wood surface by striking it with a hammer or other object is one of the oldest and most commonly used inspection methods to detect interior deterioration. Based on the tonal quality of the ensuing sounds, a trained inspector can interpret dull or hollow sounds that may indicate the presence of large interior voids or decay. Although sounding is widely used, it is often difficult to interpret because conditions other than decay can contribute to variations in sound quality. In addition, sounding provides only a partial picture of the extent of decay present and will not detect wood in the early or intermediate stages of decay. Nevertheless, sounding still has its place in inspection and can quickly identify seriously decayed structures. When suspected decay is encountered, it must be verified by other methods such as boring or coring. Practical experience has shown that sounding only works with members less than 89 mm (4 in.) thick.

Moisture Meters

As wood decays, certain electrolytes are released from the wood structure and electrical properties of the material are altered. Based on this phenomenon, several tools can be used for detecting decay by changes in electrical properties. One of the simpler tools is the resistance-type moisture meter. This unit uses two metal probes (pins) driven into the wood to measure electrical resistance, thus moisture content. Moisture meters are most accurate at moisture content levels between 12% and 22%. Pins are available in various lengths for determining moisture content at depths up to 7.6 cm (3 in.).

Although it does not detect decay, the moisture meter helps identify wood at a high moisture content level and is recommended as an initial check for suspected areas of potential decay. Moisture content greater than 30% indicates conditions suitable for decay development, unless the wood in the immediate area is treated with preservatives and there are no breaks in the treatment envelope. If inspection is conducted after an unusually lengthy period of dry weather, moisture levels in the range of 20% to 25% should be used as an indication of potentially decayed conditions.

Drilling and Coring

Drilling and coring are the most common methods used to detect internal deterioration in wood members. Both techniques are used to detect the presence of voids and to determine the thickness of the residual shell when voids are present. Drilling and coring are similar in many respects and are discussed together here. Drilling is usually done with an electrical power drill or hand-crank drill equipped with a 9.5- to 19-mm- (3/8- to 3/4-in.-) diameter bit. Power drilling is faster, but hand drilling allows the inspector to monitor drilling resistance and may be more beneficial in detecting pockets of deterioration. In general, the inspector drills into the member in question, noting zones where the drilling becomes easier, and observes the drill shavings for evidence of decay. The presence of common wood defects, such as knots, resin pockets, and abnormal grain, should be anticipated while drilling and should not be confused with decay. If decay is detected, the inspection hole can also be used to add remedial treatments to the wood. Inspection holes are probed with bent wire to measure shell thickness.

Coring with increment borers (often used for determining age of tree) also provides information on the presence of decay pockets and other voids. Coring with borers produces a solid-wood core that can be carefully examined for evidence of decay. In addition, the core can be used to obtain an accurate measure of the depth of preservative penetration and retention. To prevent moisture and insect entry, a bored-out core should be filled with a treated wood plug.

Principles of Stress Wave Nondestructive Testing

As an introduction, a schematic of the stress wave concept for detecting decay within a rectangular wood member is shown in Figure 1. First, a stress wave is induced by striking the specimen with an impact device, which is instrumented with an accelerometer that emits a start signal to a timer. A second accelerometer, which is held in contact with the other side of the specimen, serves the leading edge of the propagating stress wave and sends a stop signal to the timer. The elapsed time for the stress wave to propagate between the accelerometers is displayed on the timer.

The terms ultrasonic and sonic are often confused. The velocity at which a stress wave travels in a member is dependent upon the properties of the member only. The terms ultrasonic and sonic refer only to the frequency of excitation used to impart a wave into the member. All commercially available timing units, if calibrated and operated according to the manufacturer's recommendations, yield comparable results.

The use of stress wave velocity to detect wood decay in wood structures is limited only by access to the structural members under consideration. Stress wave velocity is especially useful on thick timbers or glulam timbers ≥89 mm (≥3.5 in.) where hammer sounding is not effective. Note that access to both sides of the member is required.

Because wood is an organic substance, material properties and strength vary in accordance with the direction in which

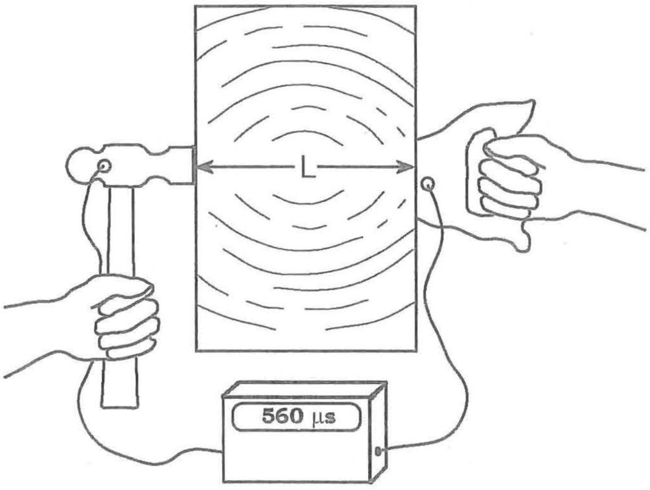


Figure 1—Schematic of stress wave timer.

the wood member is hammered compared with the cell structure orientation. Hammering the end grain of a beam or post will cause a primarily longitudinal shock wave along the length of the cell structure in the timber. Hammering the side or top of the beam will cause a wave across or transverse to the timber cells. The timber cells are arranged in rings around the center of the tree. A stress wave can pass three different ways transversely through a timber. The wave can travel perpendicular (radially) or parallel (tangentially) to the rings, or cross the rings at an angle between 0° and 90° (45° to grain).

The velocity at which a stress wave propagates in wood, as well as other physical and mechanical properties, is a function of the angle at which the fibers of wood are aligned. For most structural members, the wood fibers align more or less with the longitudinal axis of the member (Fig. 2).

Stress wave transmission times on a per length basis for various wood species are summarized in Table 1. Note that stress wave transmission times are shortest along the grain (with the fiber) and longest across the grain (perpendicular to fiber). Note that for Douglas-fir and Southern Pine, stress wave transmission times parallel-to-the-fiber are approximately 200 µs/m (60 µs/ft). Stress wave transmission times perpendicular to the fiber range from 850 to 1000 µs/m (259 to 305 µs/ft).

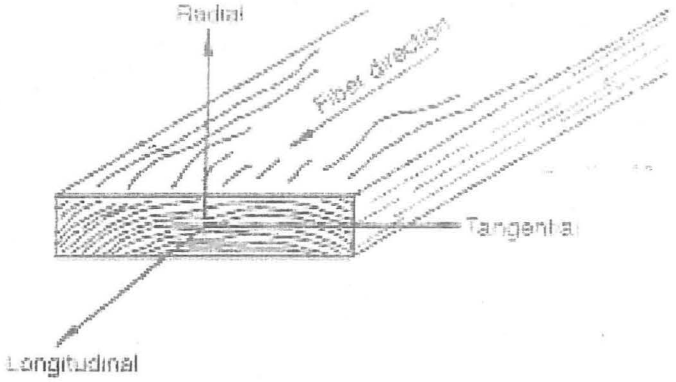


Figure 2—Three principal axes of wood with respect to grain direction and growth rings.

Table 1—Summary of research on stress wave transmission times for various species of undegraded wood

Reference	Species	Moisture content (% ovendry)	Stress wave transmission time (µs/m (µs/ft))	
			Parallel to grain	Perpendicular to grain
Smulski 1991	Sugar maple	12	256–194 (78–59)	—
	Yellow birch	11	230–180 (70–55)	—
	White ash	12	252–197 (77–60)	—
	Red oak	11	262–200 (80–61)	—
Armstrong and others 1991	Birch	4–6	213–174 (65–53)	715–676 (218–206)
	Yellow-poplar	4–6	194–174 (59–53)	715–676 (218–206)
	Black cherry	4–6	207–184 (63–56)	689–620 (210–189)
	Red oak	4–6	226–177 (69–54)	646–571 (197–174)
Elvery and Nwokoye 1970	Several	11	203–167 (62–51)	—
Jung 1979	Red oak	12	302–226 (92–69)	—
Ihlseng 1878, 1879	Several	—	272–190 (83–58)	—
Gerhards 1978	Sitka spruce	10	170 (52)	—
	Southern Pine	9	197 (60)	—
Gerhards 1980	Douglas-fir	10	203 (62)	—
Gerhards 1982	Southern Pine	10	197–194 (60–59)	—
Rutherford 1987	Douglas-fir	12	—	1,092–623 (333–190)
Ross 1982	Douglas-fir	11	—	850–597 (259–182)
Hoyle and Pellerin 1978	Douglas-fir	—	—	1,073 (327)
Pellerin and others 1985	Southern Pine	9	200–170 (61–52)	—
Soltis and others 1992	Live oak	12	—	613–1,594 (187–486)
Ross and others 1994	Northern red and white oak	Green	—	795 (242)

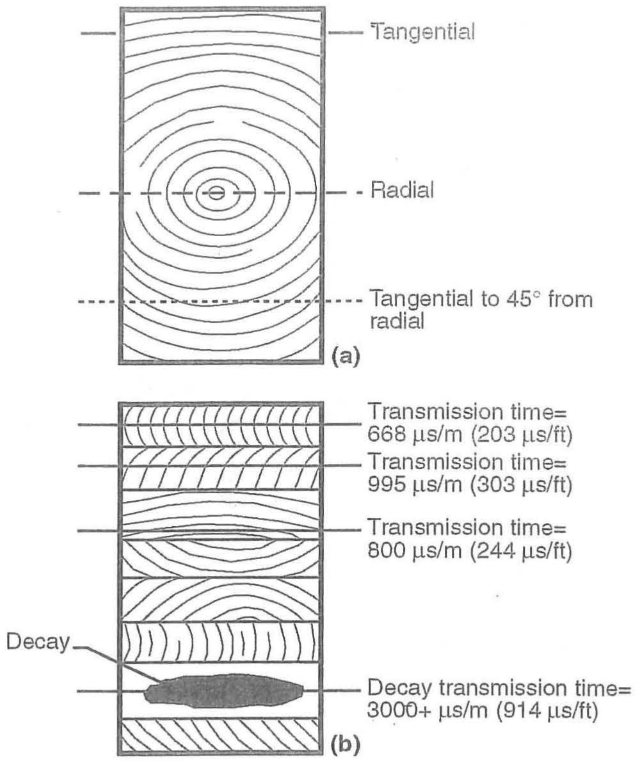

Tangential
Radial
Tangential to 45° from radial
(a)
Transmission time= 668 µs/m (203 µs/ft)
Transmission time= 995 µs/m (303 µs/ft)
Transmission time= 800 µs/m (244 µs/ft)
Decay
Decay transmission time= 3000+ µs/m (914 µs/ft)
(b)

Figure 3—Transverse stress wave paths and transmission times: (a) timber, (b) glulam beam.

Table 2—Typical stress wave transmission times for undegraded Douglas-fir at 12% moisture content

Path length		Stress wave transmission time (µs)		
(mm	(in.))	Radial	Tangential	45° to grain
64	(2.5)	43	51	64
89	(3.5)	60	71	88
140	(5.5)	94	112	139
184	(7.25)	123	147	183
235	(9.25)	157	188	234
292	(11.5)	195	234	290
342	(13.5)	229	274	340
394	(15.5)	264	315	392
444	(17.5)	297	355	442
495	(19.5)	331	396	492

Effect of Ring Orientation

Researchers have determined that the longest transverse-to-grain transmission times are found at a 45° orientation to the annual rings. The shortest time is about 30% faster in a path that is radial. Tangential transit times are expected to be about halfway between those noted previously (Fig. 3). Table 2 and Figure 4 show the stress wave transmission time for wood of good quality at 12% moisture content. These values can vary ±10% for species variation. These times are based on an assumed stress wave transmission time of 668 µs/m radially, 800 µs/m tangentially, and 995 µs/m at 45° to grain.

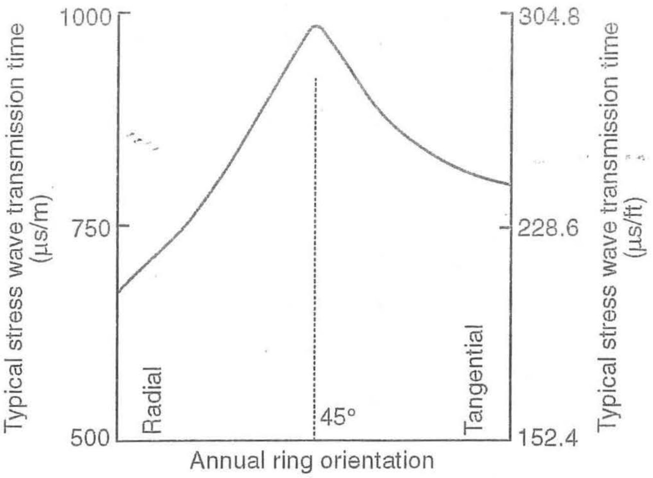


Figure 4—Transverse stress wave transmission time compared with annual ring orientation.

Effect of Decay

The presence of decay greatly affects stress wave transmission time in wood. Table 3 summarizes velocity of stress wave transmission values obtained from field investigations of various wood members subjected to degradation from decay. Note that stress wave transmission times perpendicular to the grain are drastically reduced when the member is degraded. Transmission times for undegraded Douglas-fir are approximately 800 µs/m (244 µs/ft), whereas severely degraded members exhibit values as high as 3,200 µs/m (975 µs/ft) or greater.

A 30% increase in stress wave transmission times implies a 50% loss in strength. A 50% increase indicates severely decayed wood (Fig. 5). Transverse travel paths are best for finding decay. Parallel-to-grain travel paths can bypass regions of decay.

Weight loss is not a good indicator of decay because considerable strength loss can occur without significant weight loss.

Effect of Moisture Content

Considerable work has examined the effect of moisture in wood on stress wave transmission time. Several studies have revealed that stress wave transmission times perpendicular to the grain of wood follow a relationship (Fig. 6). Note that at moisture content less than approximately 30%, transmission time decreases with decreasing moisture content. Corrections for various moisture content values are summarized in Table 4.

Table 3—Summary of research on use of stress waves for detecting decay in timber structures

Reference	Structure	Wood product	Test	Analysis
Volny 1992	Bridge	Douglas-fir glulam, creosote pressure treated	Stress wave transmission time perpendicular to grain, across laminations at 0.3-m intervals	Sound wood: 1,279 μs/m (390 μs/ft) Moderate decay: 1,827 μs/m (557 μs/ft) Severe decay: 2,430 μs/m (741 μs/ft)
Ross 1982	Football stadium	Solid-sawn Douglas-fir, creosote pressure treated	Stress wave transmission time perpendicular to grain, near connections	Sound wood: 853 μs/m (260 μs/ft) Incipient decay: – Center of members: 1,276 μs/m (389 μs/ft) – 38-mm-thick solid wood shell: 2,129 μs/m (649 μs/ft) Severe decay: >3,280 μs/m (1000 μs/ft)
Hoyle and Pellerin 1978	School gymnasium	Douglas-fir glulam arches	Velocity of stress wave transmission time perpendicular to grain, near end supports	Sound wood: 1,073 μs/m (327 μs/ft) Decayed wood: 1,574 μs/m (480 μs/ft)

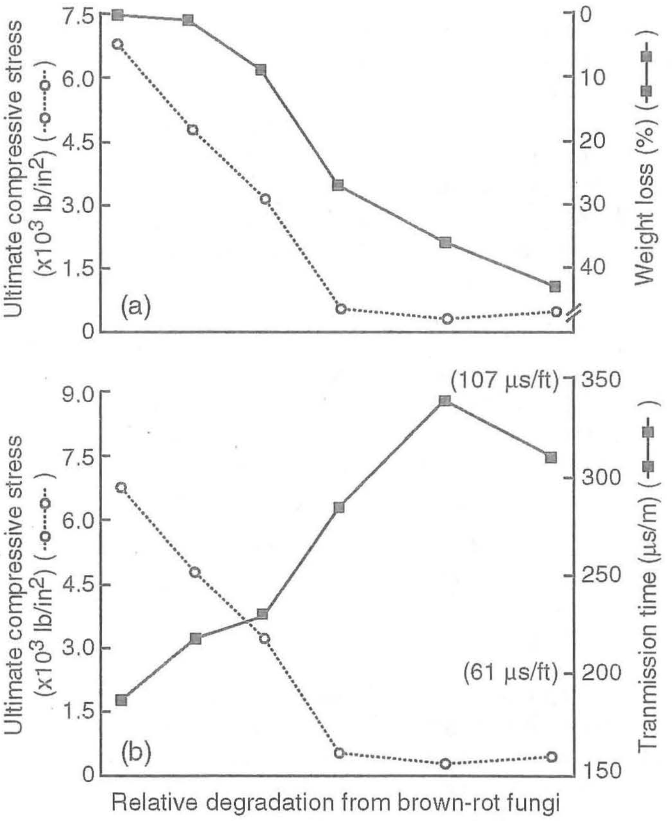


Figure 5—Relationship between stress wave transmission time and fungal degradation (Pellerin and others 1985).

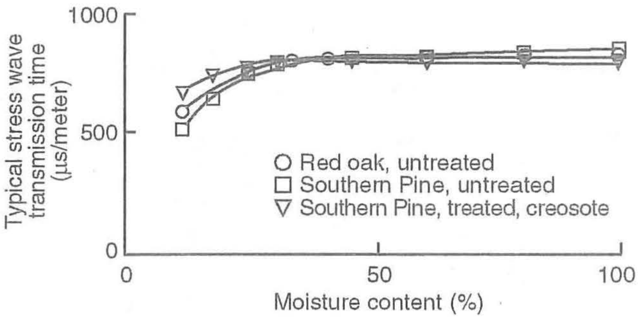


Figure 6—Transverse stress wave transmission times in Southern Pine and red oak piling.

Also note that at moisture content values greater than approximately 30%, little or no change in transmission time occurs. Consequently, there is no need to adjust the measured values for wood that is tested in a wet condition.

Effect of Preservative Treatment

Treatment with waterborne salts has almost no effect on stress wave transmission time. Treatment with oilborne preservatives increases transmission time by about 40% more than that of untreated wood. Round poles are usually penetrated to about 37 to 61 mm (1.5 to 2.5 in.), except at their ends where the treatment fully penetrates the wood. Table 5 was calculated to show expected transit time for round poles treated with oilborne preservatives. Note that although

Table 4—Stress wave transmission time adjustment factors for temperature and moisture content for Douglas-fir

Moisture content (%)	Adjustment factors			
	−18°C (0°F)	3°C (38°F)	27°C (80°F)	49°C (120°F)
1.8	0.94	0.95	0.97	0.98
3.9	0.95	0.96	0.98	0.99
7.2	0.93	0.98	1.00	1.01
12.8	0.97	0.99	1.00	1.01
16.5	0.99	1.01	1.03	1.05
23.7	1.05	1.07	1.09	1.14
27.2	1.07	1.10	1.12	1.17

Table 5—Stress wave transmission times for round poles treated with oilborne preservatives

Diameter (mm)	Stress wave transmission time (µs) for various levels of penetration[a]		
	37 mm	61 mm	Full penetration
294	222	240	300
343	254	271	350
392	286	305	400
441	321	338	450
490	350	370	500
539	386	403	550
588	422	436	600

[a] 1 in. = 25.4 mm.

these data illustrate the effect of oilborne treatments on transmission time, these values should not be used to estimate the level of penetration.

Interpretation of Stress Wave Velocity Readings

The guidelines in this document are useful in interpreting readings that are less than those for sound wood. Voids and checks will not transmit stress waves. Knots will act as parallel-to-grain wood but are usually oriented perpendicular to the long axis of timber.

Based on the direction and length of the path in the wood, wood moisture content, the presence of preservative treatment, if any, and the velocity and transit time for sound wood can be determined. For the transverse direction, note the annual ring orientation and the existence of seasoning checks.

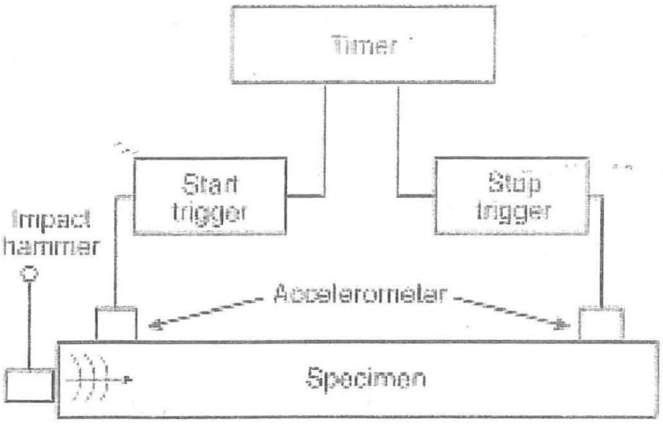


Figure 7—Technique utilized to measure impact-induced stress wave transmission times in various wood products.

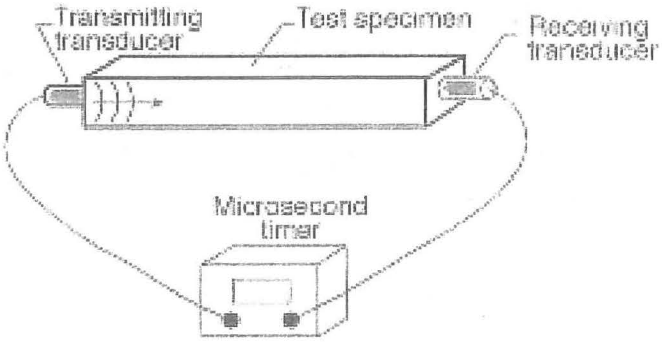


Figure 8—Ultrasonic measurement system used to measure stress wave transmission times in various wood products.

Measurement of Stress Wave Transmission Time

General Measurement

Several techniques can be used to measure stress wave transmission time in wood. The most commonly used technique utilizes simple time-of-flight-type measurement systems. Two commercially available systems that use this technique are illustrated in Figures 7 and 8.

With these systems, a mechanical or ultrasonic impact is used to impart a wave into the member. Piezoelectric sensors placed at two points on the member are used to detect passing of the wave. The time required for the wave to travel between sensors is then measured.

Commercial Equipment

The following types of commercial equipment are available to measure stress wave transmission times in wood. The manufacturer, method of operation, key considerations, and specifications for this equipment are also given.

• Metriguard Model 239A Stress Wave Timer (Fig. 9)

Manufacturer—Metriguard, Inc.; P.O. Box 399; Pullman, WA 99163; telephone (509) 332–7526; fax 509–332–0485.

Method of Operation—A mechanical stress wave is induced in a member by a hammer or other means and is detected with accelerometers at two points along the propagation path (Fig. 7). The timer starts when the wave front arrives at the first accelerometer. The timer stops when the wave front arrives at the second accelerometer and displays the propagation time between accelerometers in microseconds.

Key Considerations—It is imperative when using this equipment that the accelerometers are oriented as shown in Figure 10.

Specifications

Power requirements: 9-V battery
Resolution: ±1 μs
Dimensions: 18 by 23 by 23 cm (7 by 9 by 9 in.) high
Weight: 5.4 kg (12 lb) (including hammer and accelerometers)

A variety of testing techniques can be used to obtain values for velocity of stress wave transmission in wood members in the field. Figure 11 illustrates important aspects of field test set-ups and several commonly used techniques.

• James "V" Meter (Fig. 12)

Manufacturer—James Instruments, Inc.; 3727 North Kedzie Avenue; Chicago, IL 60618; telephone (800) 426–6500; (312) 463–6565; fax 312–463–0009.

Method of Operation—The James "V" Meter utilizes an ultrasonic pulse generator to impart a stress wave into the member. As illustrated in Figure 13, two transducers are placed on a member at a fixed distance apart. As the transmitting transducer imparts a wave into a member, the timer unit begins to time passage of the wave. When the wave reaches the receiving unit, the timer stops and displays the transit time in microseconds.

Key Considerations—Coupling of the transducers is key to obtaining reliable results. The surface of the members should be free of debris, mud, or dirt.
A coupling agent, provided by the manufacturer, is often used to facilitate the measurements.

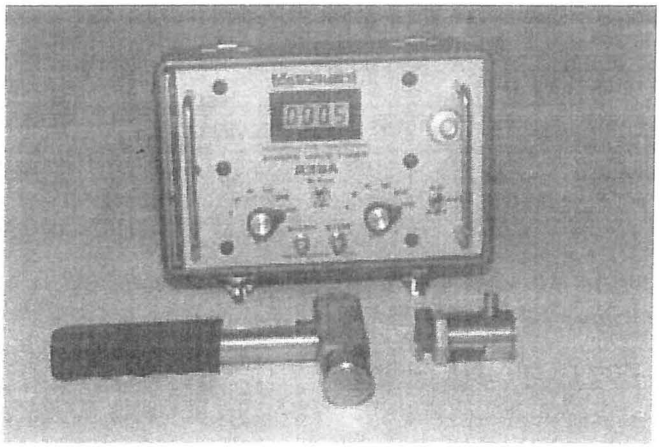


Figure 9—Metriguard Model 239A Stress Wave Timer.

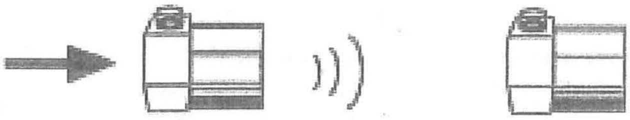

Start
Stop
Note: Wave must strike hexagonal side of accelerometer first

Figure 10—Necessary orientation of accelerometers.

Specifications

Power requirements: rechargeable NI-CAD

• Sylva Test (Fig. 14)

Manufacturer—Sandes SA, Zone industrielle, Case postale 25, CH-1614 /Granges/Veveyse, Switzerland; telephone (021) 907 90 60; fax 021 907 94 82.

Method of Operation—The Sylva test unit utilizes an ultrasonic pulse generator to impart a stress wave into a member. Two transducers are placed on a member at a fixed distance apart. A transmitting transducer imparts a wave into the member, and a receiving transmitter is triggered upon sensing of the wave. The time required for the wave to pass between the two transducers is then coupled with various additional information, such as wood species, path length, and geometry (round or square section), to compute modulus of elasticity.

Specifications

Power requirements: rechargeable batteries

Dimension: 29 by 20 by 12 cm (11.5. by 7.9 by 4.7 in.) high

Weight: 2.3 kg (5.1 lb) (instrument only) 5.7 kg (12.6 lb) (instrument with carrying bag and accessories)

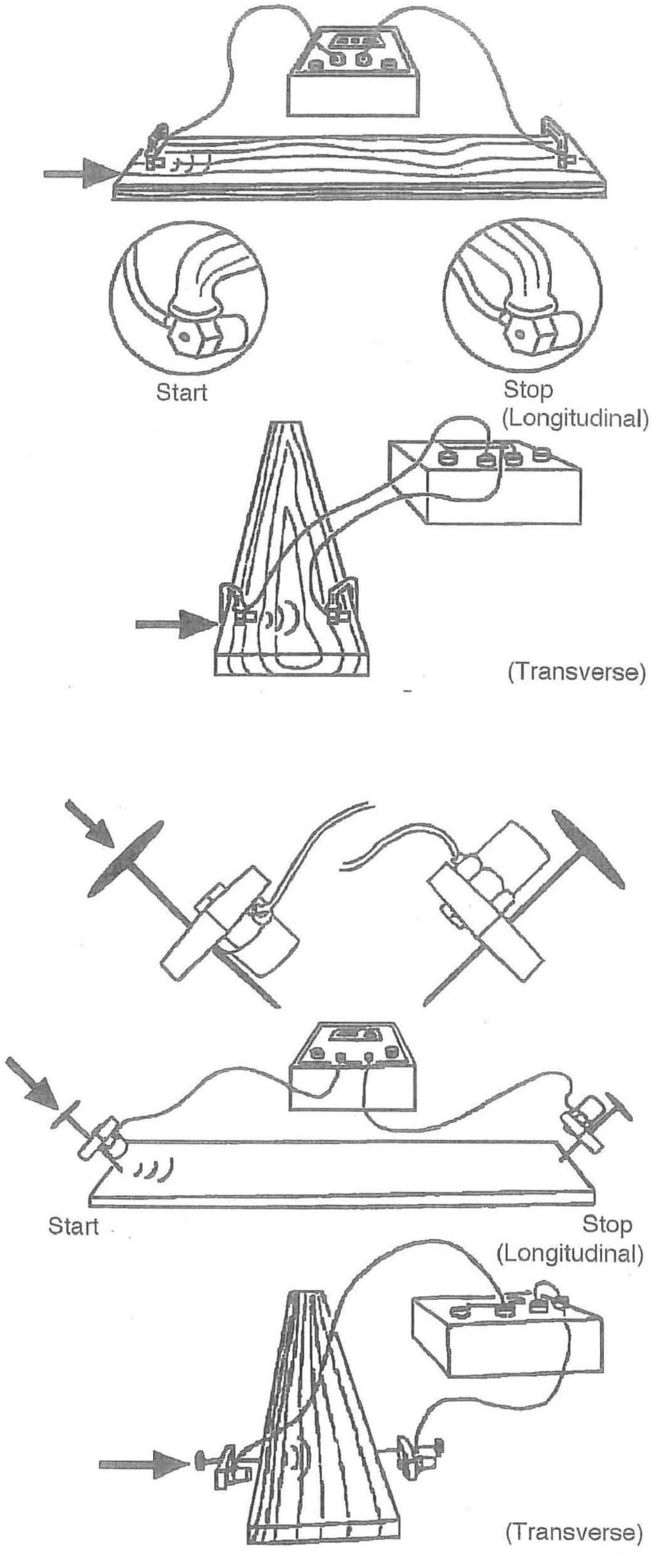


Figure 11—Important aspects of field setups for commonly used techniques.

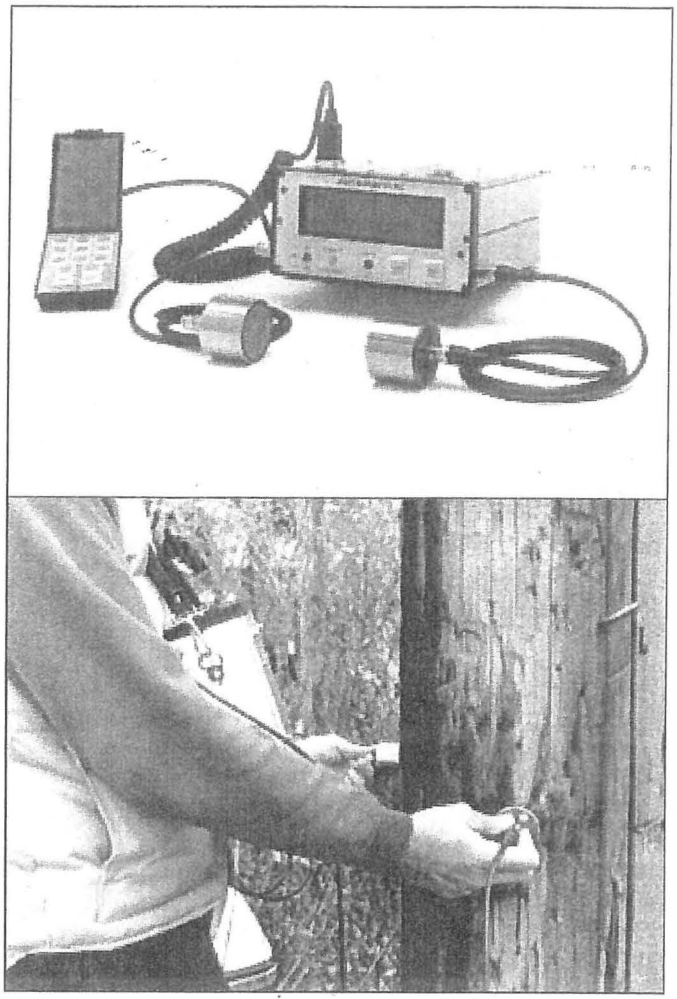


Figure 12—James V-Meter.

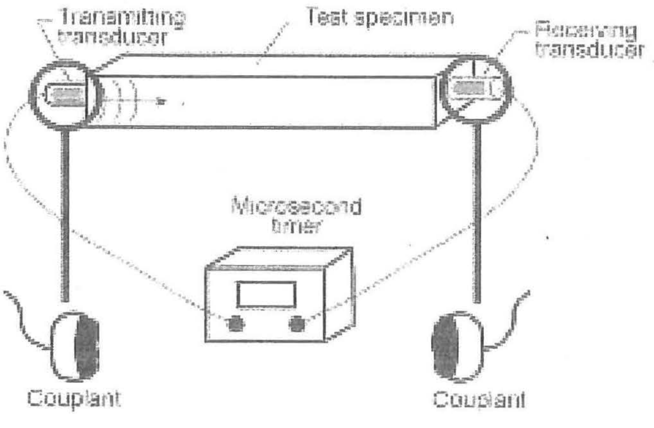


Figure 13—Ultrasonic measurement system used to measure stress wave transmission time in various wood products.

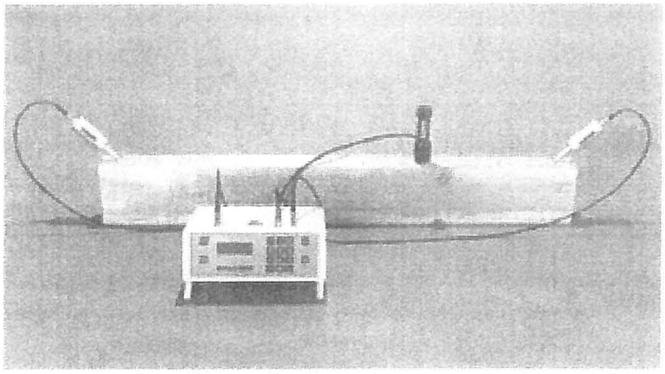


Figure 14—Sylva test.

- **Impulse Hammer—Electronic Hammer**

  Manufacturer—IML; Instrumenta Mechanik Labor GmbH; GroBer Stadtacker 2; D-69168 Wiesloch; Germany; telephone (49) 06222–8021; fax 49 06222–52552.

  Method of Operation—The electronic hammer is an instrument in which the time required for a stress wave pulse to pass through a member is measured. It uses an impact to induce a wave to flow in the member.

  Specifications

  Power requirements: 7.2-V rechargeable battery
  Weight: 4 kg (8.8 lb)

Field Considerations and Use of Stress Wave Methods

Stress Wave Transmission Time

Figure 15 outlines the general procedures used to prepare and utilize stress wave nondestructive evaluation methods for fieldwork. Before venturing into the field, it is useful to estimate stress wave transmission time for the size of the members to be inspected. Preceding sections provided information on various factors that affect transmission time in wood. This information can be summarized, as a starting point, by simply using a baseline transmission time of 1,575 µs/m (480 µs/ft). A transmission time (per length basis) less than this would indicate sound material. Conversely, transmission time greater than this value would indicate potentially degraded material. Using this value, the transmission time for a member can be estimated by knowing its thickness (path length) and the following formula:

$$T_{\text{baseline}}\,(\mu\text{s}) = 1300 \times \text{WTD}$$

where

T_{baseline} is baseline transmission time (µs), and

WTD is wave transmission distance (path length) (m).

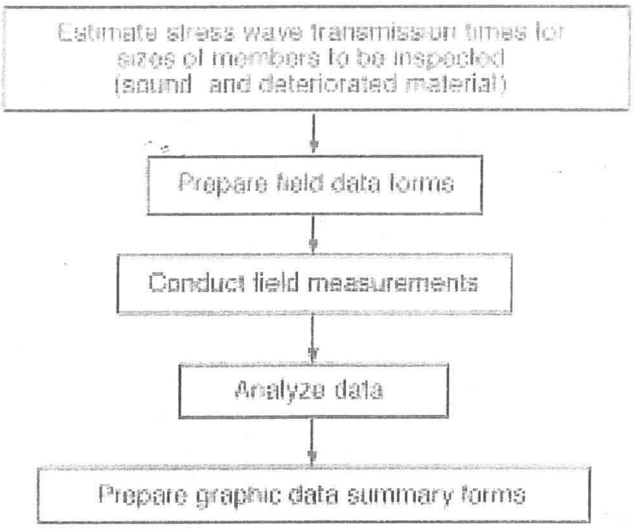

Estimate stress wave transmission times for sizes of members to be inspected (sound and deteriorated material)
Prepare field data forms
Conduct field measurements
Analyze data
Prepare graphic data summary forms

Figure 15—General procedures used to prepare and use stress wave timing methods for field work.

[Conversion to English (inch–pound) units: 400 × WTD, where WTD is wave transmission distance (path length) in feet.]

Note that we chose lower values to be conservative. By knowing this number for various thicknesses, fieldwork can proceed rapidly.

Field Data Form

An example of a typical field data acquisition form is included in the Appendix. Key items to include on the form are the name, location, and number of the structure, name of inspector, and date of inspection.

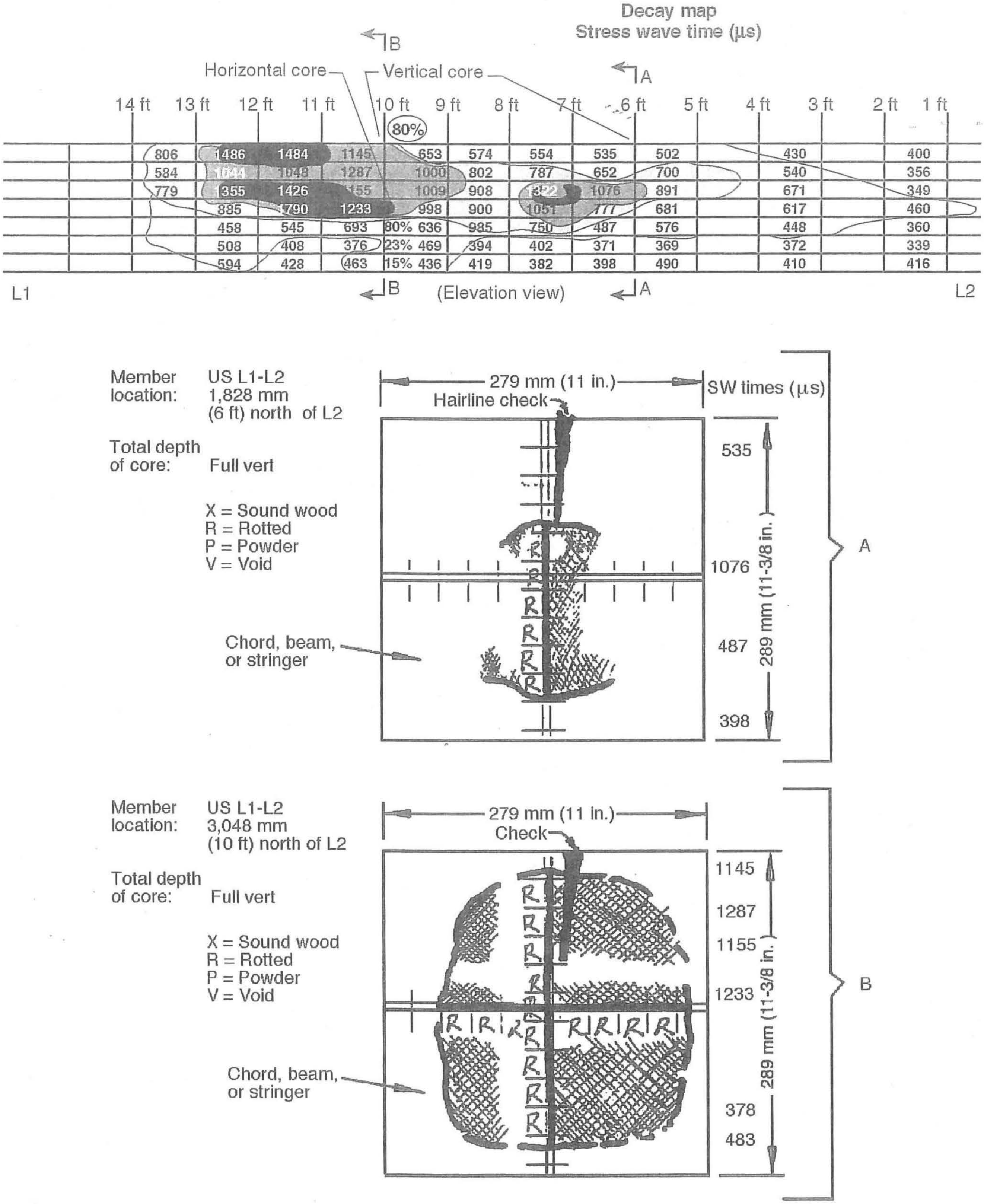
Field Measurements

Field use should be conducted in accordance with the instructions provided by equipment manufacturers. In the field, extra batteries, cables, and sensors are helpful. Testing should be conducted in areas of the member that are highly susceptible to decay, especially in the vicinity of connections and bearing points.

Note that the baseline values provided serve as a starting point in the inspection. It is important to conduct the test at several points at varying distances from the suspicious area. In a sound member, little deviation is observed in transmission times. If a significant difference in values is observed, the member should be considered suspect.

Data Analysis and Summary Form

Data should be presented in an easy-to-read manner. Figure 16 illustrates various data summary forms, which readily show the presence and extent of degradation.



806	1486	1484	1145	653	574	554	535	502	430	400
584	1044	1048	1287	1000	802	787	652	700	540	356
779	1355	1426	1155	1009	908	1322	1076	891	671	349
	885	1790	1233	998	900	1051	777	681	617	460
	458	545	693	80% 636	985	750	487	576	448	360
	508	408	376	23% 469	394	402	371	369	372	339
	594	428	463	15% 436	419	382	398	490	410	416

Member location: US L1-L2 1,828 mm (6 ft) north of L2

Total depth of core: Full vert

X = Sound wood
R = Rotted
P = Powder
V = Void

Member location: US L1-L2 3,048 mm (10 ft) north of L2

Total depth of core: Full vert

X = Sound wood
R = Rotted
P = Powder
V = Void

Figure 16—Examples of overall summary form (top) and data summary form (sections)(bottom).

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Appendix—Acquisition Form and Additional Reference Material

This Appendix includes an example of a typical field data acquisition form. Additional reference material on wood properties and stress wave theory is also provided.

Page ________ of ________

Data Log—Stress Wave Transmission Times

Structure's name ____

Location ______________________________ Date ____________________

______________________________ Equipment ____________________

______________________________ ____________________

______________________________ ____________________

Inspector ____

Member	Location	WTD	Equipment reading (µs)	Transmission time (µs/m) (µs/ft)	Condition	Grain orientation

Page __________ of __________

Data Log—Stress Wave Transmission Times

Member	Location	WTD	Equipment reading (μs)	Transmission time (μs/m) (μs/ft)	Condition	Grain orientation

Additional Reference Material

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